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THE FIRST BOOK

IN

PHYSICS

BY

J. A. CULLER, PH.D.

PROFESSOR OF PHYSICS IN MIAMI UNIVERSITY, OXFORD, OHIO

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PREFACE

THIS is an elementary book intended for the higher grammar grades or the early part of the high-school course. It is all devoted to a study of important principles in physics, and it is expected that such a study will pave the way for a more comprehensive work in physics which is to follow. But, even if the study of physics is pursued no further than that presented in this book, the student will have gained some important fundamental ideas which will be of great service to him during his life.

There appears to be a great deal of confusion as to the proper presentation of physics in the high-school. Results do not seem to be satisfactory as the subject is generally taught. Various remedies are being proposed from time to time, but none have met with general acceptance.

As it appears to the author, the source of nearly all the difficulty arises from the fact that in physics, as presented in the third or fourth year of the high-school, more new ideas and new methods of thought and expression are thrust upon the student at one time than in any other branch taught. The result is that the average student is frequently hopelessly confused, and, as the lessons multiply, the confusion increases. Take, for example, the study of the inclined plane. The student, in a lesson, is supposed to learn that the inclined plane is a machine; that the ratio between height and length of the incline is the same as that between force and weight, when force is exerted parallel to the incline; but the ratio of height to base must be considered when the force is applied parallel to the base. He must be able to draw a line which shall represent in magnitude and direction the force of gravity on the body, and then resolve this into two components which shall represent in magnitude and direction the forces parallel and perpendicular to the direction along which the primal force acts. He is to see in the same lesson that the general law of machines is applicable to the inclined plane, and must be ready to work all sorts of problems, including those of the screw and wedge. To add to the difficulty, the metric system only may be used, and it, probably, has been encountered for the first time when the study of physics began.

None of these things are beyond the comprehension of a student in the fourth year of his high-school course; but, when they all come at once, the student is often confused and overwhelmed.

The remedy for this is not the use of an easier text-book, but the gradual introduction of the subject in previous years. This should be done by the use of such a book as this one in the hands of the student, that he may learn to *read* and *think* as well as to *listen* and *think*. The use of the book will also insure more systematic work, and will be found more satisfactory in every way than the method of occasional oral instruction by the teacher.

After such a study of principles of physics, the student has a store of ideas which will be a great aid to him when he undertakes a more serious study of the subject later on.

J. A. CULLER.

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THE FIRST BOOK IN PHYSICS

INTRODUCTION

The subjects that belong to physics.— Physics is one of the most important branches of science. Many times every day we make use of some of its principles. All the motions of our bodies, whether in work or play, are made in accordance with these principles.

The act of throwing a ball, running, skating, rowing, climbing a tree, swinging, falling, and so on, are all acts which may be explained by the principles and laws treated of in physics.

All bodies fall to the earth; water runs down hill; winds blow; and the earth revolves about the sun. These are all problems in physics.

Then there are a great number of machines which man uses in doing his work. The plough, wagon, locomotive, lathe, hammer, saw, wind-wheels, water-wheels, sail-boats, steam-ships, sewing-machines, derricks, and so on, all are machines which have been made in accordance with principles and rules of physics.

The great subject of heat and how it affects matter is also treated in a book of this kind. Why does water sometimes boil, and at other times freeze? Why does a piece of metal become longer when it is heated, and shorter when it is cooled? Why do we build a fire in an engine when we want it to run? Why does the air pass up a hot chimney and make the stove "draw"? Why do we fan ourselves when we wish to cool off? These and many other questions of this kind are answered in physics.

Sound, light, magnetism, and electricity are all subjects of great interest and importance, and all belong to this branch of science.

In a machine shop.—In any large manufacturing shop you can see many of the applications of the rules and principles of physics. The fire under the boilers makes the heat which changes the water to steam; the steam then makes the engine run; the engine turns a long shaft and many wheels from which belts run to numerous machines. The machines are all built up according to the laws of physics.

The hum and whir of the machines, the conversation of the men, the signals of the steam-whistle, and the jingle of call-bells, all show that sound, too, is an important help in the big factory. Then there are numerous lights throughout the shop, so that the men may work at night or on dark days. These lights are made by an electric current. If the shop is a modern one, electricity may be made to do a great number of things. All the belts may be taken out, and the machines be made to run by the use of electric motors. In that case the engine must work just as hard, for it

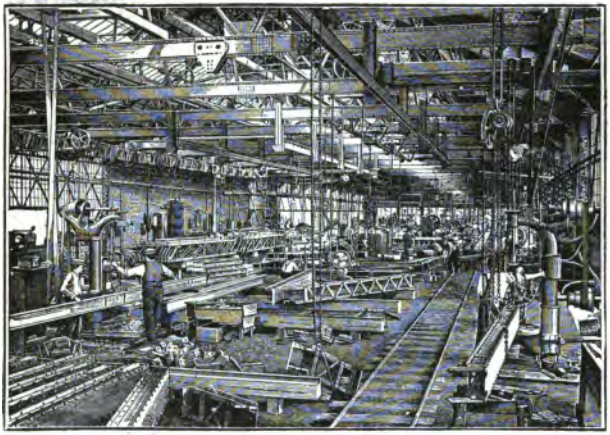

FIG. 1.—A manufacturing shop. (From "Modern Mechanism.")

must run the dynamo that makes the current.

Nearly everything that you would see in the shop that we have just described belongs to this subject of physics.

Scope of this book.—This book is a physics, but it is intended for those who take up the subject for the first time. The most important branches of physics are presented here, but only in such a way as to lead up to a deeper study of the same subject at a later time.

It is very desirable that every one who studies this book should perform, if possible, all of the experiments. Physics is an experimental study, and physical principles are always better understood when the experiments which illustrate them are made.

It is a benefit to see an experiment made but it is always better for one to make an experiment for himself. The apparatus needed is all very easily made, except some parts which may be purchased at a small expense. The pupil who completes this book and performs the experiments will then be ready to undertake a more systematic study of physics.

Matter.—Matter is anything that we can see or feel; or, matter is anything that can occupy space. Water, air, iron, wood, coal, glass, and so on, are all forms of matter. Our own bodies are made of material substances. When we study the next chapter, we will try several experiments, and from them we will learn several of the properties of matter.

Energy.—Energy is the ability to do work. A man has a great deal of energy if he is able to do a great deal of work. No matter whether he *does* the work or not, if he is *able* to do it he has the energy.

A clock-spring contains energy when it is wound up, and it may be able to do the work of making the clock run for ten days. Energy is always found in matter, if it is found at all; and it is a very important thing, for by it all the work of the world is done.

Physics is all about matter and energy, and the use that is made of them.

CHAPTER I

SOME OF THE PROPERTIES OF MATTER

When we speak of a *property* of any kind of matter, we mean some quality or peculiarity which it possesses. For example, *hardness* is a property of many solids. Also, some metals can be hammered into very thin sheets or drawn into very fine wires. Such qualities are called properties.

Several important properties of matter are given below.

First property of matter.—*Two bodies of matter cannot be in the same place at the same time.* This property is common to all matter. Every one knows from his own experience that this is so. When one is hurt by bumping his head against a door, striking his fist against a wall, or falling heavily onto the ground, it is because that space was already occupied by other matter. Such is the cause of nearly all the accidents from which we suffer.

It is plain that this is true for all solids and liquids, but it may not be so plain that it is just as true for gases. So we will try an experiment.

Experiment 1.—Secure a bottle that will hold about one pint. The mouth should be about one inch in diameter. Fit into the mouth a cork through which two holes have been made, one for a straight, or bent, glass tube, and the other for a small funnel. Put into place as shown in Fig. 2.

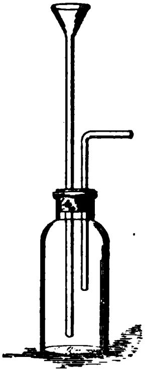

FIG. 2.—Bottle arranged for experiment with air.

Now hold the finger upon the end of the tube and pour water into the funnel. Why does the water not run down into the bottle? It seems that the bottle is already full of something, and for this reason the water cannot get in.

Remove the finger from the end of the tube and the water will at once run down into the bottle.

Wet the finger and hold it just above the tube and air will be felt coming out as the water runs in. We see, then, that the bottle was full of air, and the water and air could not both be in the bottle at the same time.

Now remove the funnel and put a glass tube in its place. There are now two plain tubes through the cork. Place the mouth over one of them and try to force air into the bottle while the finger is pressed upon the other. Some air will be forced in, although the bottle was full to begin with. This is because air is easily compressed, just as a pillow or sponge may be pressed into smaller space, but no additional air can be forced into the bottle without compressing the air which it already contains. If the finger be now removed, the air will come out as fast as it is blown in.

Remarks.—The holes can easily be made in the cork by cork-borers, if they are at hand; but if not, a rough hole may be made with the small blade of a knife and then smoothed out with a round file.

The cork and tubes must fit air-tight. To make sure of this, the cork may be boiled in water for a minute or two till it is quite soft, and then pressed into the mouth of the bottle. The boiling should be done after the holes are bored.

The glass tubes and funnel can be secured from the chemical laboratory or from any drug-store.

Some thoughts on the experiment.—It is plain from the experiment that air is matter, for matter is anything that can occupy space. What is true of air, in this respect, is just as true of any gas or vapor.

There are some forms of matter, then, that cannot be *seen*. Everything that we can see is matter, but all matter cannot be seen. Steam is a vapor of water and cannot be seen. People sometimes say they can see the steam coming from a tea-kettle or a steam-engine. What they see, however, is not steam, but millions of fine droplets of water which were formed by cooling the steam. If you will notice the spout of the tea-kettle, you will see that the steam as it first comes out is invisible; but as soon as it is slightly cooled, the steam condenses into fine drops

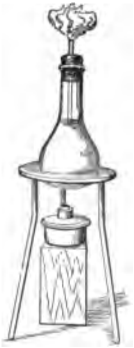

FIG. 3.—The steam coming from the glass tube at the top of the bottle cannot be seen until it condenses.

which look like fog, and, in fact, are the same as fog. (Fig. 3.)

We also learn from the experiment that when we squeeze a gas into any space it tries to make room for itself. When you blow air into a foot-ball, the sides are pushed out to make more room. When steam is let in at one end of a cylinder, it pushes the piston to the other end that the steam may have more room. So in many ways we make a great deal of use of the principle that two bodies of matter cannot be in the same place at the same time.

A second property of matter.—*When a body of matter is let alone, it will continue to do whatever it is doing.* This property of matter is called *inertia.* When matter is at rest it will remain at rest, and when it is in motion it will continue on in a straight line forever, unless something stops it or changes its motion. Matter does not want to stop when it is in motion any more than it wants to start when it is at rest.

Experiment 2.—Place a strip of light paper, about one-half inch wide and two inches long, upon the end of the finger, and place a penny or nickel upon it as shown in the figure. Now wet a finger of the other hand and strike rapidly down upon the free end of the paper.

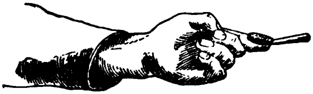

FIG. 4.—To remove the paper and leave the coin on the finger.

The strip of paper will be removed, leaving the coin upon the end of the finger. (Fig. 4.)

Experiment 3.—Throw a ball, stone, or any mass of matter, and try to answer the question, why does it continue to go after it has left the hand?

Experiment 4.—Secure a block of wood which will weigh three or four pounds and drive a tack into one end of it. Tie to the tack a piece of common light thread. By pulling gently on the thread the block can be dragged across the top of the table. By a sudden jerk upon the thread the string will be broken and the block will be moved very little. The inertia of the mass of matter in the block prevented it from making a sudden start, and so the string was broken in the attempt to overcome the inertia. (Fig. 5.)

Some thoughts on Experiments 2, 3, and 4.

In Experiments 2 and 4 the body was at rest, and did not, apparently, want to start. In Experiment 3 the body, after being set in motion, did not want to stop. Inertia is the name applied to this property of matter.

When the ball was thrown from the hand it continued its flight in the air for some time.

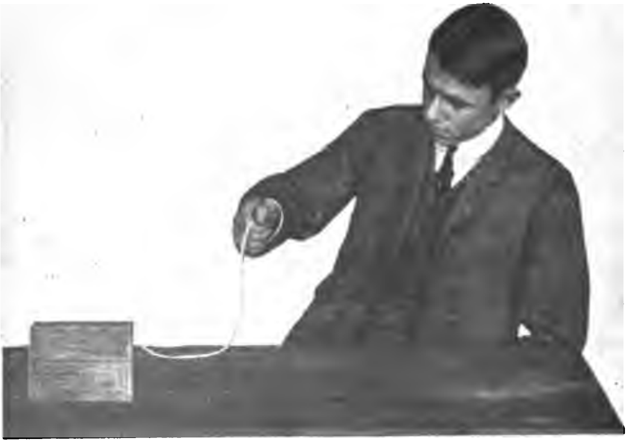

FIG. 5.—Inertia of a block of wood.

If everything had let it alone, it would have continued on in a straight line forever. But it is never possible to throw a ball under these conditions. The air always offers some resistance to it, and gravity is always present to pull it to the earth, so that the ball is soon made to strike against some other object and is brought to rest.

We have to deal with the inertia of matter in many ways every day we live.

If we attempt to get onto a moving carriage or train, we are in danger of being hurt by the sudden jerk needed to give our bodies the same motion as the train. When we get off a moving train, our bodies will continue their motion, and we may be injured in trying to bring ourselves to rest.

The inertia of a train of cars is very great. The locomotive must puff vigorously to get the train started. Little by little the inertia is overcome, and the train moves faster and faster till it gains a speed of sixty miles an hour or more. When the next station is reached, the brakes must be applied to overcome the inertia again and bring the train to a standstill.

An interesting application of the principle of inertia is seen on some railroads in the method of taking water up into the tender while the train is running. A trough about 400 yards long, 18 inches wide, and 6 inches or more in depth, is placed in the middle of the track and kept full of water. When the train, which may be running thirty or forty miles an hour, reaches the trough, the engineer lets down a scoop beneath the tender, and a pipe leads from the scoop to the water-tank in the tender. The inertia of the water prevents it from suddenly starting as fast as the train is moving, and so it slides up the pipe into the tender.

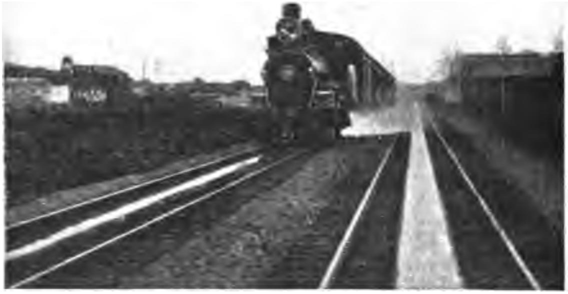

FIG. 6.—Locomotive taking water while running.

When the mass of matter is large, it requires a large force to give it a swift motion in a short time. A cannon-ball often weighs more than a ton. The force of the powder behind it must be very great to overcome the inertia of the ball and give it sufficient velocity before it leaves the cannon. If the powder should burn too rapidly, the cannon would burst. This is why cannon are made so long and the grains of powder so large. Some grains are as large as the fist. The powder does not all burn at once, but continues to burn and push upon the ball to the end of the cannon. In this way the inertia is gradually overcome, and the ball may leave the cannon with a velocity of 2000 or more feet per second.

Inertia is a property of all matter.

A third property of matter.—*All matter is porous* Even such hard substances as steel, glass, diamond, stone, and so on, do not occupy all the space they seem to. They are all made up of a great number of very small particles called molecules, and these molecules are all separated a little distance from each other. It is in that sense that matter is said to be *porous*. We sometimes call a substance porous when it is full of holes

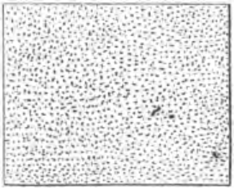

FIG. 7.—A representation of molecules highly magnified, with the spaces between them.

and passages for liquids, as in a sponge or porous earth. But it is in a different sense that we are using the word *porous* here. Gold, glass, iron, and all forms of matter are full of *pores*, which are the spaces between the molecules. There are many millions of molecules in a body of matter as large as a pinhead, and so the spaces between them must be very small. It is not possible with the strongest of microscopes to see either the molecules or the spaces between them, because they are so very small.

The molecules are all the time in motion back and forth, moving faster when they are warmed, and slower when they are cooled. They may be pressed closer together, or may move farther from each other.

We can now understand how it is that all matter can be compressed into a smaller space. Some substances, like air, are very easily compressed.

Experiment 5.—Use a bicycle-pump which has a close-fitting piston. Hold the rubber tube shut and thrust down the piston. It seems like pushing down upon a coiled spring, and when the pressure is removed the handle will fly back to its first position. This experiment shows that air is very compressible and also very elastic.

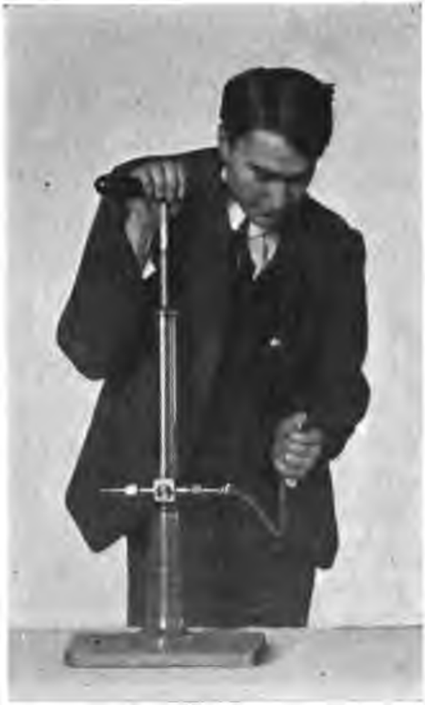

FIG. 8.—Compression of air.

All gases are very compressible. Their molecules can be pushed closer and closer together without much resistance from them, but when the pressure is removed, they will bound back from each other.

All substances are compressible to some extent, but some, such as water and steel, very strongly resist any attempt to push their molecules any closer together.

A fourth property of matter.—*Hardness.* Solids are often distinguished from each other by the property of hardness. Some substances, such as lead and soapstone, can be easily scratched with the finger-nail. The hardest substance is the diamond. A diamond will scratch any other solid. A small chip of diamond is often fastened to a handle, as shown in Fig. 9, and used to cut glass. Each substance has a degree of hardness peculiar to itself.

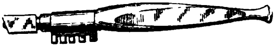

FIG. 9.—Diamond glass-cutter.

A fifth property of matter.—*Many metals and some other substances may be hammered out into thin sheets or drawn into fine wires.* A metal that can be hammered into a thin sheet is said to be *malleable*. Gold is a very malleable metal. Sheets of gold can be made so thin that it takes 4,000,000 of them to make a stack one inch high.

When a metal can be drawn into a fine wire, it is said to be *ductile*. Gold, silver, platinum, and copper are very ductile metals. Platinum wires are made so fine that they can scarcely be seen with the naked eye.

Experiment 6.—Get at the hardware store about twenty or thirty feet of soft iron wire. It should be about the size of ordinary broom wire, but must be soft and flexible. Fasten one end to a screw or nail and wrap the other end about a stick. Stretch the wire out straight and mark its length on the floor or pavement wherever the experiment is tried. Now grasp the stick and pull steadily on the wire, noting the increase of length. Continue to pull until the wire breaks, and measure the total increase in the length. If the increase in length be divided by the first length of the whole wire in feet, the quotient will be the increase in length per foot. Iron is quite ductile, but not nearly so much so as some other metals. When the wire is drawn out longer, it, of course, becomes thinner, for there is no more iron in it then than before.

A sixth property of matter.—*Matter, as a rule, tends to crystallize.* Nearly all kinds of substances, when in a solid form, show a tendency to arrange their molecules in a definite way, thus producing crystals. When the molecules are free and have plenty of room, very beautiful and perfect crystals are often formed.

When water freezes it always crystallizes, though the crystals are not easily seen in a solid block of ice because they are crowded so closely together. When a fine mist freezes in the air, snow-flakes are formed, which are very beautiful in form and can be plainly seen.

Experiment 7.—Take a pane of glass about 8 x 10 inches in size, and place it out where it will become cold as ice or colder. When light dry flakes of snow are falling, catch a few of them on the cold glass and examine them. They will remain for some time in a perfect form unless the heat from your breath melts them. A magnifying-glass will assist in bringing out the beauty of the crystal.

No two flakes can be found exactly alike, but all are alike in a general way. All have six arms radiating from the centre.

In the figure several different forms of snow-flakes are shown. In performing the experiment described above, many other forms may be observed and drawings made of them.

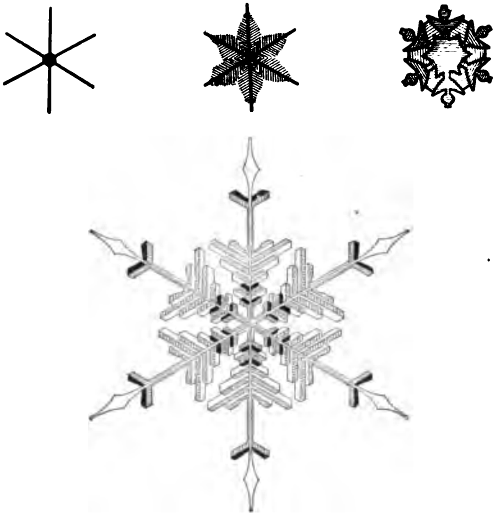

FIG. 10.—Snow-flakes.

The crystals of ice require more room than the water before it was frozen. This is why freezing water expands and often bursts the vessel which contains it. Even strong iron pipes will easily be burst by freezing the water which they contain.

Many beautiful crystals of other substances are quite common. In Fig. 11 may be seen the form of crystal of several substances. Many substances on changing from a liquid to a solid will crystallize, as is the case with water, cast iron, zinc, and so on.

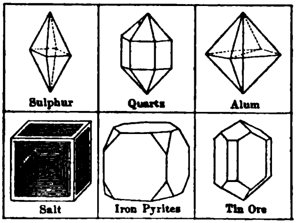

FIG. 11.—Various forms of crystals.

Many substances, when dissolved in water and set aside, will slowly crystallize on any point to which the crystal can easily attach itself. Rock-candy is made in this way.

Experiment 8.—Make a small basket of copper wire which is well covered with cotton insulation. Such wire can be secured from the physical laboratory of the high school, or at any good hardware store or electrical store.

It may be bent into any form or pattern desired. Then dissolve about one pound of alum in a quart of hot water. Suspend the basket in the solution so that it hangs free from the sides of the vessel, and set aside in a quiet place for twelve hours or more. On lifting the basket out, it will be covered with a mass of beautiful alum crystals.

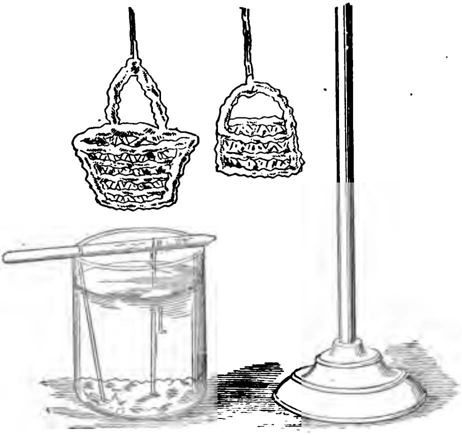

FIG. 12.—Alum crystals.

A seventh property of matter.—*Matter exists in the condition of a* **solid,** *a* **liquid,** *or a* **gas,** *depending upon its temperature.*

Water is a good example of a substance

that readily changes from one state to another when the temperature changes. Ice may be considered as solid water. A little heat will easily change it to a liquid, and still more heat will change the liquid to a gas.

People who live in hot countries near the equator never see solid water in nature, though they may freeze water with ice machines.

People who live near to the north or the south pole have ice, or solid water, during the greater part of the year.

We are used to iron as a solid because it will remain a solid unless the change of temperature is very great. When it is placed in a very hot furnace it will readily change to a liquid, and if heated still hotter it will change to a gas.

We are used to air as a gas because it stays in that state through all ordinary changes of temperature. But when air is made sufficiently cold it turns to a liquid, and when made still colder it becomes solid.

All substances can be made to pass from one state to another when the change in temperature is sufficiently great.

QUESTIONS

1. Name a number of subjects that are discussed in a book on physics.

2. What is matter?

3. What is energy?

4. Where is energy always found?

5. How could you prove that there is energy in your body?

6. What is meant by a property of matter?

7. State the first property of matter.

8. How could you show that air is matter?

9. Can all matter be seen?

10. Can steam be seen?

11. State a second property of matter.

12. What is this property called?

13. How can you show by experiment that a body at rest tends to remain so?

14. When you throw a ball, why does it not continue on in a straight line?

15. What accident have you ever had as a result of this property of matter?

16. How can a locomotive fill its tank with water while running?

17. Why are cannon made so long?

18. State and explain a third property of matter.

19. What are molecules?

20. Name and explain a fourth property of matter.

21. State a fifth property of matter and give examples.

22. How could you show by experiment that iron wire is ductile?

23. State a sixth property of matter.

24. Describe an experiment for the crystallization of alum.

25. State a seventh property of matter.

26. Why is iron nearly always found to be in a solid state?

CHAPTER II

GASES. THE AIR

The nature of a gas.—The molecules of a gas are not so close together and do not attract each other as in the case of liquids and solids. The molecules of a gas are all the time trying to get farther apart. If only a few cubic inches of any gas be set free in a large room, it will expand till it entirely fills the room. The molecules will then be much farther apart, but they will be evenly distributed throughout the room.

In liquids and solids the molecules cling to each other and resist any force which would pull them apart. This is an important difference between gases and other forms of matter. The air is the most important gas with which we have to do, so that the greater part of this chapter is about the atmosphere in which we live.

Our place on the earth—The earth is composed of solids, liquids, and gases. The soil, rocks, and ores form the solid parts.

The water covers about three-fourths of the solid earth. The air forms a great atmosphere about the whole earth. The outside of the earth is at the top of the air. We live, then, not on the surface of the earth, but *in* the earth at the bottom of the atmosphere. We live in a great sea of air, and cannot live outside of it. Fishes can live only in a sea of water.

FIG. 13.—Liquid, solid, and gas.

Our sea—the air—is quite light, and so we scarcely know it is there as we move through it from place to place. But when the air is in rapid motion, as in strong winds and storms, we know it can move with great force.

Even when the sea of air is quiet, if we attempt to move rapidly through it we know that it resists our motion, as water resists the motion of a moving ship. A swift bicycle rider finds that his speed is checked by the air through which he moves, and a fast train must use considerable power in overcoming the resistance of the air through which it speeds on its way.

Weight of air.—The earth draws all matter towards its centre. This is the cause of weight. Air is matter, and of course it has weight. This may be easily shown by the apparatus seen in Fig. 14. The hollow globe is hung from one arm of the balance, and weights are placed in the pan to just balance the globe. The globe is then lifted off and the air pumped out of it. When it is now put back in place again it will be considerably lighter than before. If the stopcock be opened and the air admitted, the balance will be restored. It is found that one cubic foot of air at sea-level will weigh 1.28 ounces. This would be only $\frac{1}{778}$ as heavy as water, and yet

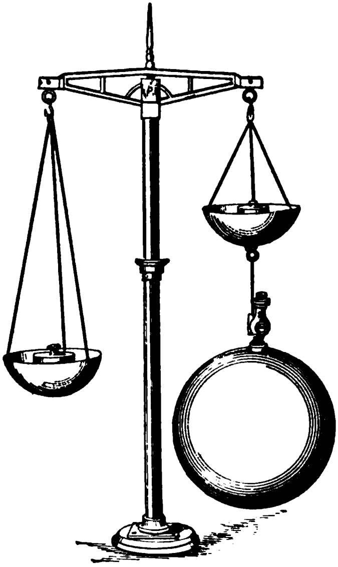

FIG. 14.—Weighing air.

there is so much of the air that its whole weight is very great.

Experiment 9.—Measure the length, breadth, and height of your room in feet. Multiply these numbers together and you will have the contents in cubic feet. Multiply the number of cubic feet by 1.28 and you will have the weight in ounces. Divide by 16 and the quotient will be the number of pounds of air in the room. If you live very high above sea-level, your air is lighter; but for most localities this calculation will give you very nearly the correct result.

All gases very compressible.—All gases can easily be squeezed into smaller space. The amount of gas in any space depends on the amount of pressure upon it. The amount of pressure at sea-level is nearly fifteen pounds on every square inch. If a quantity of air be enclosed in a cylinder, as shown in Fig. 15, then, when the piston is loaded with fifteen pounds more to every square inch of its surface, it will be pushed half-way down the cylinder. That is, when the load is doubled, the volume is one-half as great. If the load is made three times as great, the volume of the air will be only one-third as great, and so on.

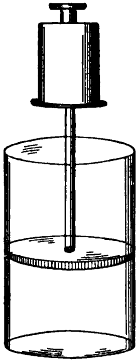

FIG. 15.—Air enclosed in a cylinder, compressed to half its volume by making the pressure upon it twice as great.

Water is very different from air in this respect, for it is difficult to show that water can be compressed at all. The same pressure that will reduce the volume of air one-half will reduce a volume of water only .00005.

The lower air under great pressure.— The ocean of air is quite deep and extends up for a long way above the land and water. The height of the air has never been determined, but one would probably have to go up a distance of about 1000 miles before he would be entirely beyond the air. All this great mass of air is pressing down upon the air which is next to the land and water, so, as we might expect, the lower layers are very much compressed and contain more air in a cubic foot

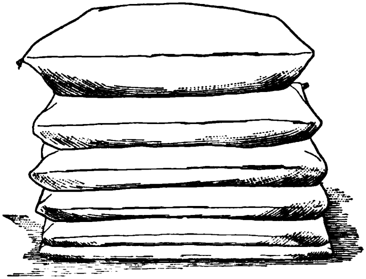

FIG. 16.—Stack of pillows. Illustrating the cause of pressure and density of lower layers of air.

than other layers higher up. This condition may be represented as shown in Fig. 16. Here are a number of pillows filled with light feathers and piled one on top of another. Each pillow contains the same quantity of feathers, but in the lower ones they are compressed into much smaller space by the weight of those above. We say that the air is most dense at the bottom because there more air is compressed into the volume of a cubic foot or cubic inch than at any place higher up. If all the air were as dense as that at sea-level, the atmosphere would not be more than five miles high. Some of the highest mountain peaks would then be entirely above the upper surface of the sea of air. But the air grows less and less dense as we go up until it shades off into nothing. There is no level surface on the top of the sea of air as there is on the top of a sea of water.

Pressure of the air in all directions.—At any point in a gas or liquid, the pressure is equal in every direction. This may be shown by the following experiment:

Experiment 10.—Secure from your dentist a piece of rubber dam about three inches square and tie it tightly over the mouth of a small funnel, as shown in Fig. 17. Attach a short piece of rubber tubing to the tube of the funnel. Close your lips over the rubber tube and withdraw some of the air from the funnel. The rubber dam will bulge in because part of the air-pressure is removed from the inside, but that on the outside remains the same as before. Pinch the rubber tube so the air cannot get back into the funnel, and hold the funnel in various positions. The rubber will be pressed in with equal force whether the mouth of the funnel is up, down, or sideways, showing that the pressure is equal in all directions.

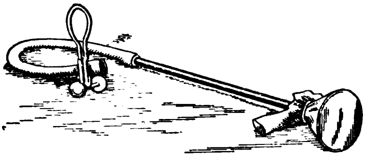

FIG. 17.—To show that air-pressure is equal in all directions.

Pressure of the air at sea-level.—At the level of the sea the air presses in every direction nearly fifteen pounds on every square inch. From this you can calculate that the pressure on your body is very great. The whole surface of the body of a good-sized man is about sixteen square feet. His body must then be under the enormous pressure of about seventeen tons. Why do we not feel this great pressure, and why does it not crush the body? The pressure is equal on all sides of the body, and there is air in the tissues and cavities of the body, which is pressing outward as much as the outer air is pressing inward.

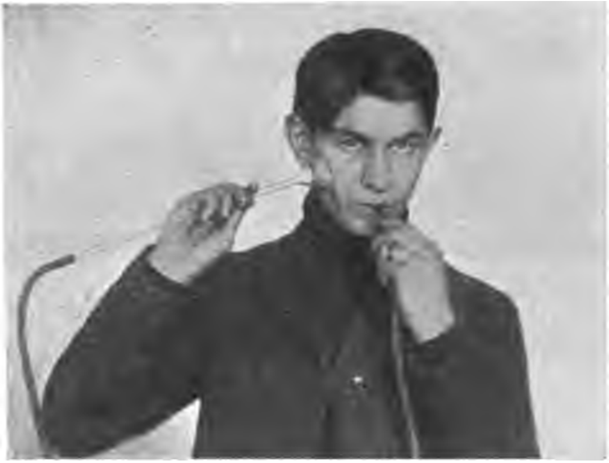

FIG. 18.—Air-pressure partly removed from the outer side of the cheek.

The following experiments will give some idea of the air-pressure:

Experiment 11.—Place the mouth of a small funnel lightly against the cheek, and by suction withdraw some of the air. The cheek, we say, is drawn into the funnel, but it is more correct to say that the cheek is *pushed* into the funnel. The air-pressure was partly removed from the outer side of the cheek, but remained unchanged on the inner side.

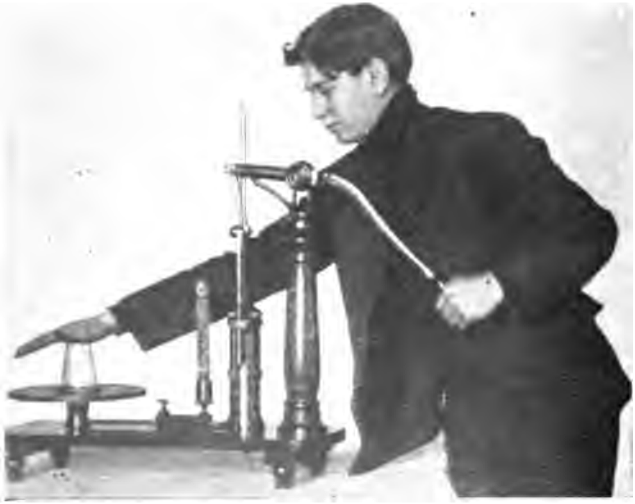

FIG. 19.—Pressure removed from palm by air-pump.

Experiment 12.—Those who have use of an air-pump can show the pressure of the air in a still more striking manner. Use the same apparatus as in Fig. 18, but attach the tube to the air-pump.

Do not, in this case, apply the funnel to the cheek, as there is danger of raising a blister or leaving a mark. Instead, place the palm over the funnel and then work the pump. The pressure is nearly all removed from the palm, but remains in full force on the top of the hand, tending to press it into the funnel. The hand is pushed from above.

Experiment 13.—Get at the harness-shop a circular piece of pliable and rather heavy leather. It should be about two inches in diameter. Fasten a string to the centre of the rougher side of it by stitching into the leather, but not through it.

Cut a piece of glass about three by five inches and smear the centre of one side of it with vaseline, and press the leather flat upon it. Now lift on the string, and the glass will be raised. Tie a weight, such as a brick, to the glass, and the brick will be raised also. The object of the glass is to furnish a smooth surface, and the vaseline makes the leather fit air-tight. The leather may be attached directly to any smooth block, as in Fig. 20.

This apparatus is often called a "boy's sucker." The string raises the centre of the leather disk, while the edges remain in contact with the glass. Thus a part of the air-pressure is taken off the upper side of the glass, while it all remains on the lower side. The difference in pressure will more than equal the weight of the glass and brick.

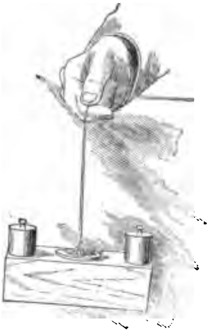

FIG. 20.—Lifting block and weight with a "boy's sucker."

Experiment 14.—Draw one end of a piece of glass tubing to a fine point. Insert the tube tightly through a cork and fit the cork to the mouth of a bottle which will hold about one quart. The cork must fit air-tight. The point of the tube should extend a little way into the bottle. Fit a short piece of rubber tubing onto the outer end of the glass tube.

If an air-pump be at hand, use it to draw the air from the bottle, but if not, then use the mouth instead, and extract as much of the air as possible. Pinch the rubber tube between the thumb and finger, and invert the bottle in such position that the end of the tube will be below the surface of water, as shown in Fig. 21. Release the tube, and the air-pressure will force the water up into the bottle, producing what is called a fountain in vacuum.

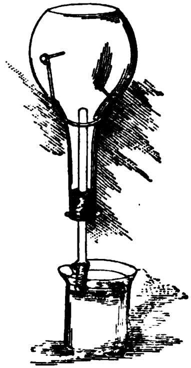

FIG. 21.—Air-pressure causing fountain in the flask.

A lifting pump.—We can now readily understand how it is that an ordinary pump can raise water from a well by the aid of air-pressure.

A pump consists of a long hollow stock of wood or iron (*S*, Fig. 22) extending into the water at its lower end. At the bottom of the stock is a valve, *B*, which opens upward only. Several feet above this valve is the "sucker," *A*, which can be moved up and down, but must fit the stock closely. Upon the sucker is another valve, which also opens only upward. When the sucker is raised, it lifts the air-pressure off the water inside the stock, and the pressure outside then pushes water up through the lower valve. When the sucker is now pushed down, the water will start to run back through the lower valve, but in doing so will close it. At the same time the valve in the sucker will open and let out some of the air between it and the lower valve. When the sucker is again raised, still more pressure will

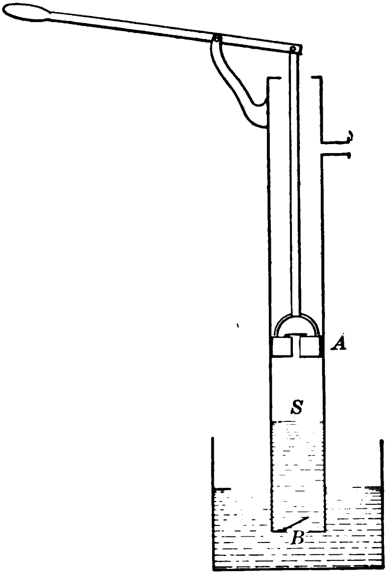

FIG. 22.—Lifting pump. The sucker is ascending. The pump is just being started and the water has not yet reached the sucker.

be lifted off above, and more water will be forced in below. This operation is continued until the water is pushed by the air up through the sucker and can then be lifted to the spout above, where it runs out. Such a pump is called a lifting pump. The air-pressure pushes the water up to the sucker, and the sucker lifts the water the balance of the distance. The sucker must never be more than thirty-four feet above the water in the well, even in the very best of pumps. It is best to have it only ten or fifteen feet above the water.

The force-pump.—The force-pump also uses the air-pressure to get the water up part of the distance, but it then *forces* the water up the rest of the way, while a lifting pump lifts the water out after it gets above the sucker. The arrangement of the force-pump is shown in Fig. 23. *A* is a solid plunger or piston. It does not have any valve. There are two valves in a force-pump, as there must be in any pump. One is at the bottom of the pump-stock, just as in the lifting pump; the other is a little above it and opens outward into the pipe, *C*. When the plunger is raised, the air-pressure is partly removed from the water inside the stock, and water is pushed, by the outside pressure, in through the lower valve. Now, when the plunger is forced downward upon the water, the lower valve will be closed, and the only opening through which the water can get out is through the valve which opens into the pipe, *C*. Thus the water is *forced* out.

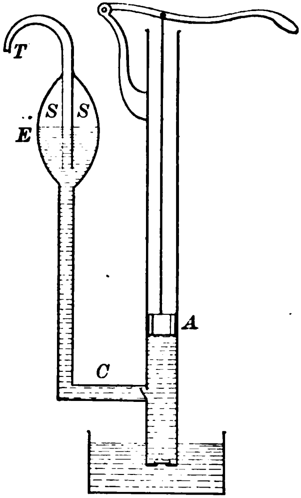

FIG. 23.—Force-pump. The plunger, *A*, is descending.

Elasticity of gases.—When any gas is enclosed in a vessel and pressure is put upon it, as shown in Fig. 15, it will readily be compressed; but as soon as the pressure is removed it will expand to its original volume. Because a gas will do this perfectly, it is said to be perfectly elastic. When a great deal of a gas is squeezed into a small space, it will press out in all directions just as hard as the pressure is upon it.

Experiment 15.—Fill a quart bottle or flask about one-third full of water. Into the neck of the bottle fit a cork, through the centre of which passes a glass rod. The rod must reach nearly to the bottom of the bottle and extend two or three inches above the cork. The top of the glass rod must have been previously drawn to a fine point, so that the hole is very small. This can easily be done by holding the rod in an alcohol or Bunsen flame, or in the flame of a gasoline stove, about one inch from the end, and as soon as the glass becomes soft the end can be pulled off. This will draw the end of the rod to a fine point, and, as soon as

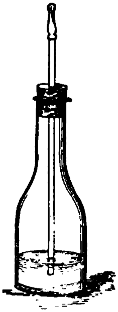

FIG. 24.—Fountain from increased pressure within the bottle.

it is cooled, a small piece of the point can be pinched off, leaving a small hole in its centre.

The cork and rod thus prepared must fit tightly into the bottle.

Now place the lips over the top of the tube and force as much air as possible into the bottle. Make use of the muscles in the cheeks to assist in forcing the air in. On taking the mouth away, the water will spurt to a considerable height from the fine hole in the tube and will continue for some time. By slipping the tube of a bicycle-pump over the top of the glass tube, more air can be forced into the bottle, and when the rubber tube is removed the water will come out with sufficient force to strike the ceiling.

The action of the air in the bottle is explained in this way: More air than usual was compressed into the space within the bottle, and since the air is perfectly elastic, it pressed hard against the walls of the bottle and down upon the water to get more room. The bottle was strong enough to resist the pressure, but water could get out through the tube. By making the opening at the top of the tube very small, the water could not get out rapidly, and so the fountain continued for some time. As soon as the air got enough room it quit pressing on the water, and so the fountain ceased.

Some uses of elasticity of gases.—The elasticity of gases is made use of in many ways in the practical affairs of life. For example, it is useful in the attachment to the force-pump described above. The force-pump throws the water out in spurts. It is much better to have a steady stream of water. This can be secured by making an attachment (*E*, Fig. 23) to the tube of the pump. The water is pumped into the chamber, *S S*, and compresses the air there. The air then pushes steadily down upon the water and forces a steady stream out of the spout at *T*.

Another common use of this principle is in the air-gun. Here a considerable amount of air is compressed into a small chamber by pulling down a lever. The air then pushes out in all directions with great force. A bullet is then placed in the barrel of the gun in front of the air. By pulling a trigger, the air is allowed to press against the bullet, which is thus sent out with great speed. It is the elastic force of the air—that is, its struggle for more room—that pushes the bullet out.

When air is pumped into a bicycle-tire it is this same elastic force that pushes out in all directions and makes the tire stiff.

In some machine shops, air is compressed in large steel tanks. Pipes lead from the tanks to various parts of the shop, where the air is made to run small engines or other machines.

Steam is a gas, and when a great deal of it is crowded into a boiler it struggles violently for more room. This is what makes it valuable for running locomotives and all sorts of steam-engines.

The barometer.—We have already explained that air has weight, and the great sea of air is very deep. Of course, then, there would be great pressure at the bottom of the air where we live. At sea-level it amounts to about fifteen pounds per square inch. At any point higher than sea-level the pressure would be less, because the air is not so deep there. The air often changes from place to place, so that the pressure does not remain the same at any point for any great length of time. The barometer is an instrument by which the air-pressure at any time or place can be measured.

A common kind of barometer consists of a glass tube about thirty-six inches long and closed at one end. This tube is filled with mercury and turned upside down, with its lower end in a bottle of mercury. Mercury is used because it is a very heavy liquid, being 13.6 times heavier than water. A column of mercury thirty inches high will press down at the bottom with a force of fifteen pounds on every square inch. This is the same as the air-pressure per square inch, so we see they will balance each other. If the air becomes heavier, it will push more mercury into the tube and the mercury will rise. If the air becomes lighter, some mercury will run out into the bottle and the mercury will fall.

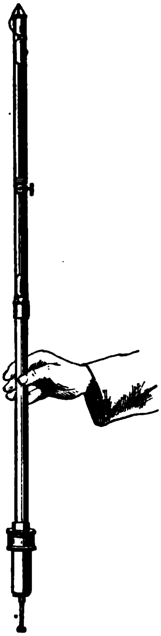

FIG. 25.—A barometer.

So we see that whenever the mercury rises in a barometer, we know that the air must be heavier, and whenever it falls, the air must be lighter.

Water might be used in a long tube for a barometer, but the tube would have to be more than thirty-four feet long, and so it would be inconvenient.

Experiment 16.—It is not very difficult to make a fairly serviceable barometer at small expense.

Select a glass tube with fairly heavy walls, about thirty-six inches long. The diameter of the bore need not be more than one-eighth of an inch. Heat the tube about one inch from one end in an alcohol, a Bunsen, or a gasoline flame till the glass becomes soft, and pull the end off, thus closing the end of the tube. Keep the end of the tube in the flame until it becomes rounded and smooth, and lay it aside till it is cool.

Have ready one-half pound or more of clean mercury, and a medicine dropper.

The next step is to fill the tube with mercury and boil it in the tube. This part of the work must be done carefully. All air and moisture must be driven out of the mercury, for there must be no gas of any kind at the top of the tube when the barometer is completed.

Take a little mercury into the medicine dropper and insert it into the tube, letting the mercury run slowly down to the closed end of the tube. Put in only enough to fill the tube for a distance of about one inch. Hold the tube in an inclined position, as shown in Fig. 26, and gently heat the mercury until it boils. When it begins to boil, be careful not to overheat it, as it will splutter and fly up the tube. A little experience will soon teach one how to put it into the flame or take it out as the need

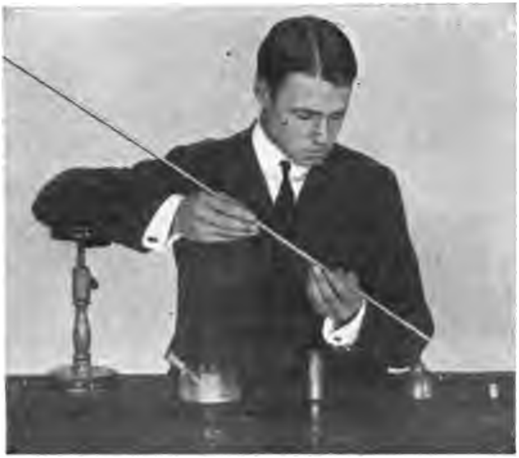

FIG. 26.—Boiling mercury in a barometer tube.

may be. Do not be in a hurry and do not grow impatient. It will need to be boiled only a few seconds. Examine the mercury in the tube, and if any bubbles can be seen, it must be boiled a little longer. If the mercury appears clear as a mirror, it is boiled enough, and that much is now done.

Now, by use of the medicine dropper, put in enough more mercury to fill the space of another inch, and boil it as before. So continue, inch by inch, until the tube is filled. When the tube is nearly full, it must be handled with care, as any awkward move may break the tube, and then the work will all have to be done over again. Even if you do break a tube or two and spill some mercury, try again and keep on trying, and you will be sure to succeed.

The tube must be full and heaped up, but the last inch need not be boiled, as it will run out into the bottle when the tube is turned upside down.

The next step is to invert the tube without spilling any of the mercury, and to place it so that the open end is down and beneath the surface of mercury in the bottle. To do this, first have ready a small bottle with a mouth large enough to receive the tube very loosely.

Fill the bottle about one-half full of mercury. Now prepare two strips of thin leather, or chamois skin, each about four inches long and one-fourth inch wide. Fold these across each other over the open end of the tube, and hold firmly to the four ends in the manner shown in Fig. 27. Invert the tube and push the open end down into the mercury in the bottle, meanwhile holding tightly to the leather strips. Now hold the tube in an upright position and carefully draw out the strips.

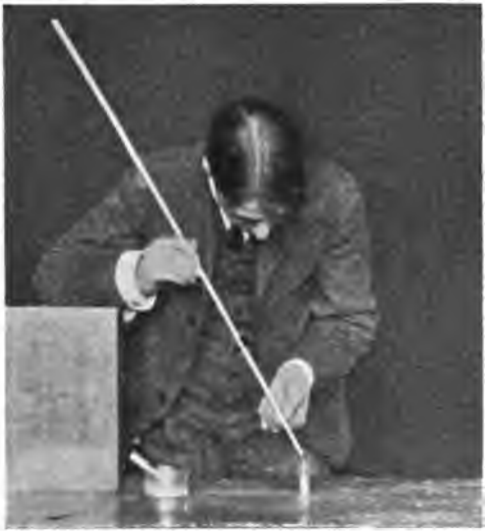

FIG. 27.—Inverting the barometer tube.

The closed end of the tube is now at the top, and the open end is down in the bottle.

As the tube was about thirty-five inches long, the mercury will fall nearly five inches from the top. The distance from the top of the mercury in the tube down to the surface of the mercury in the bottle will be nearly thirty inches. This column of mercury just balances the air-pressure, and the instrument is now a complete barometer. Whenever the air-pressure changes, the height of the mercury in the tube will change.

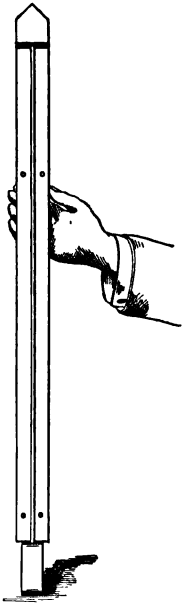

FIG. 28.—Barometer mounted in frame.

The instrument must now be mounted in a frame of some kind and fastened to the wall. This should be prepared beforehand, so that when the barometer is ready, it may at once be mounted and put in place.

The frame may consist of wooden strips about 37 inches long, 2 inches wide, and ½ inch thick. Fasten them together with cross-pieces at the top and bottom, leaving a space between the long strips just large enough to receive the tube. The lower cross-piece should be thicker than the top one, so that it may be gouged out behind to make room for the bottle.

Fasten the frame with screws to the wall of a room or out on the porch. Then take it down, place the barometer into it, and gently raise all to the place which has been made ready for it, and fasten the screws.

Make a mark on the frame opposite the top of the mercury. Find out from some one who has a good barometer, what its height in inches is at that time, and mark that number on your barometer. Then mark the half inches and quarter inches a short distance above and below that mark. Observe from day to day the rise or fall of the mercury.

What the barometer tells us.—The only thing that the barometer measures, or tells us, is the air-pressure. But we have learned that when the mercury rises, the weather will be fair, and when it falls, the weather will be foul. Why is this? When the mercury falls, that means that the air-pressure is light at that point, and so the air from other points, where the air is heavier, will flow towards the point of light pressure.

When you dip a bucket of water from a large tubful, the water will flow in from all sides and make the pressure the same in all directions. In the same way the heavier air will flow to the place where the pressure is less. This is the cause of all the winds. If the mercury in the barometers in Pennsylvania is high, and if the barometers in Ohio are low, we know that the wind will blow from Pennsylvania to Ohio. Winds usually bring rain and storm. That is how a barometer helps us to foretell rain. Winds will blow away from points where the barometer is high, and so the high barometer means fair weather.

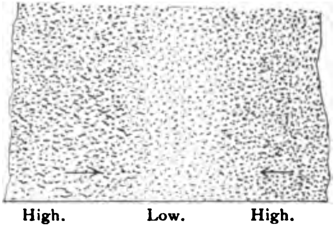

FIG. 29.—A representation of the difference in air, causing high and low barometer. The arrows show the direction the air will move.

The Weather Bureau has about one hundred and sixty stations in as many different cities throughout the United States. Those who are in charge of these stations must make a record twice every day, of the height of the barometer, the amount of moisture in the air, the direction and velocity of the wind, and the amount and kinds of clouds.

These facts are telegraphed to Washington, D. C., every morning at 8 o'clock, and every evening at the same hour. From these a map is made, from which it is possible to predict the weather a day or more in advance. Reports of the probable state of the weather is telegraphed to all parts of the United States.

The most important part of the record is that of the barometer, and from it alone a safe estimate can be made of the coming weather.

How to measure the height of a mountain.—We have explained that the pressure of the air is due to the great amount of it, all of which is drawn towards the centre of the earth by gravity. Of course, then, if you would go to some high point, as on the top of a tall building or upon a mountain, there would not be so much air above you, and so the pressure would not be so great. If you would carry with you a barometer such as we have described, you would find that the mercury would fall about one inch for every nine hundred feet you would go up a mountain. If you would continue to climb till the barometer

FIG. 30.—The height of a mountain.

had fallen five inches, you would know that you were 4500 feet higher than when you started.

Why a balloon goes up.—The lower any point is in the air, the greater the pressure will be in all directions. The bottom of a balloon is deeper down in the air than the top of it, so it will be pressed harder upward on the bottom than downward on the top. If the balloon is light, this greater upward pressure on the bottom will make it ascend. A balloon must always be filled with some gas which is lighter than air. It would be better if a balloon had nothing in it at all; but then the pressure of the air on the outside would crush it, and if it were made strong enough to resist the air-pressure, it would be too heavy. So the best balloons are made as light as possible and filled with hydrogen, the lightest gas. An ordinary balloon, such as is often seen at a county fair, is filled with hot air, which is lighter than cool air.

FIG. 31.—**Balloon.**

Experiment 17.—It is not difficult to make soap-bubbles in such a way that they will ascend as balloons. First prepare a good soap solution by dissolving any good soap in rain water. Test the solution by blowing, in the ordinary way, some bubbles with a smoking-pipe. If bubbles as large as six inches in diameter can be blown, the solution is good enough for this experiment.

Now blow some bubbles with hydrogen, and they will rapidly ascend to the ceiling. To do this, secure a four-ounce bottle with a fairly good-sized mouth. Fill it half-full of water, and put into the water a small handful of pieces of zinc. Scraps of sheet zinc can be had at any tin-store and may be cut into small pieces. Some old piece of zinc that has been used under the stove will do very well. Bore the cork and pass a glass tube through it, so as to make a close fit. The tube should extend an inch or two above the cork, but need not extend below. Fit a piece of rubber tubing over the top of the glass tube and onto the stem of an ordinary tobacco-pipe. Have

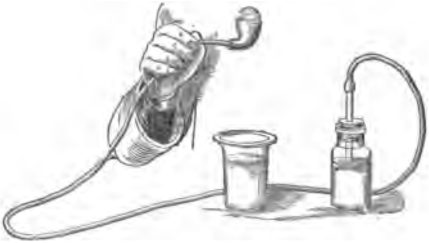

FIG. 32.—Soap-bubble balloons.

the soap solution in a saucer near by. Now pour into the bottle about one teaspoonful of strong hydrochloric acid and insert the stopper. Dip the bowl of the pipe into the soap solution and hold as in Fig. 32. When a bubble is formed, it will pull itself loose, or a quick jerk of the pipe sidewise will set the bubble free. Why does it go up?

Why a chimney draws.—If you understand why a balloon ascends, you can easily understand why a chimney draws. When air is warmed it becomes lighter, and since the pressure below it is greater than the pressure above it, it is *pushed* up, just as the balloon filled with warm air is pushed up. A chimney does not *draw*. The air is not *pulled* up the chimney, but the greater pressure below pushes it up.

Experiment 18.—Secure a tall lamp chimney and place it over a short piece of burning candle (as shown in Fig. 33) so that plenty of air can get in below. The candle-flame will heat the air, and the air-pressure below pushes it out at the top of the chimney.

The movement of the air can be made visible by smoke. The smoke is best made by burning touch-paper. Such paper is easily prepared by dissolving about one tablespoonful of saltpetre in one-half pint of water. In this dip any soft paper, such as cheap tablet-paper, and hang it up to dry. Strips of this paper can be tightly rolled, and when one end is lighted it will char and smoke, but will not blaze. Examine the draft in the chimney by the use of such paper.

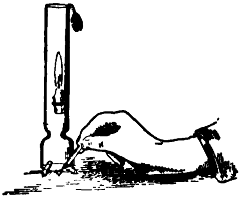

FIG. 33.—Draft upward.

Now remove the candle, and after the chimney is cool, place a chunk of ice in its place. Test with the touch-paper again, and it will be found that the air is now moving down through the chimney. The ice makes the air colder, and so heavier than the outside air. While the touch-paper is held in the chimney its heat will cause an upward draft; but when the paper is removed, the smoke that remains

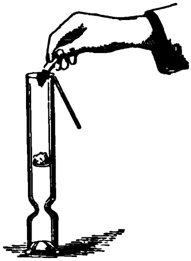

FIG. 34.—Draft downward.

will sink to the bottom of the chimney, showing that the ice alone causes a downward draft. The cold air falls just as a balloon which is too heavy will fall to the ground. The air-pressure is still greater at the bottom of the chimney, but gravity pulls the cold air downward harder than the air pushes upward.

Composition of air.—Air is composed of several different gases in about this proportion:

Oxygen	20.96	per	cent.
Nitrogen	78.00	“	“
Argon.	1.00	“	“
Carbon dioxide	.03	“	“
Ozone	.01	“	“

These gases are all mixed very evenly together. The gases of the air are not united to each other chemically, but are simply mixed, much as wheat, oats, barley, and beans might be well mixed together in a bushel basket. The oxygen is the most important gas of the air, and we must get some of it in every breath we draw. In fact, the only use in breathing is to get oxygen. The nitrogen is an inactive, lazy gas. It does us no good to breathe it, but it prevents our getting too much oxygen. The argon is still more inactive than the nitrogen. The carbon dioxide is a very necessary food for vegetables, and so little of it is mixed with the outdoor air that it does no harm to breathe it.

If a gallon each of oxygen and nitrogen were put together in a larger vessel, then, without shaking the vessel, the two gases would quickly mix themselves together so that there would be equal parts of each in all parts of the vessel. This action of the gases is called *diffusion.* Because of diffusion there is no chance that the air at one place may be all oxygen and at another place all nitrogen or carbon dioxide. At any point in pure air each gas will be present in the proper proportion.

QUESTIONS.

1. How do the molecules of a gas differ from those of a solid or a liquid?
2. What is our place on the earth?
3. Do we live on the outside of the earth?
4. What is the weight of a cubic foot of air?
5. How could you calculate the weight of air in your room?
6. What is the air-pressure at sea-level?
7. How can you show that air is very compressible?
8. How deep is the air?

9. Why is the air more closely packed near the sea-level than in the upper regions?

10. Show that the air presses equally in all directions.

11. Why does the air-pressure on your body not crush you?

12. In Experiment 11, was the cheek *drawn* or *pushed* into the funnel?

13. Explain how the "boy's sucker" lifts the brick.

14. What causes the water to rush into the bottle in Experiment 14?

15. Draw a section of a lifting pump on the black-board and explain how it works.

16. Draw a section of a force-pump on the black-board and explain how it works.

17. What uses are made of the elasticity of gases?

18. For what is a barometer used?

19. Describe a simple barometer.

20. Why is mercury used in a barometer?

21. Why must the mercury be boiled?

22. How can you make a barometer?

23. What does a barometer tell us about the weather?

24. How may a barometer be used to find the height of a mountain?

25. Why does a balloon ascend?

26. Why does a chimney draw?

27. What is the composition of air?

28. Why do we breathe air?

29. Of what use is carbon dioxide?

30. How are the gases in the air mixed?

CHAPTER III

LIQUIDS. WATER

Difference between liquids and gases.—Liquids act like gases in many respects, but several properties of liquids are very different from those of the gases. The molecules of a gas, as we have explained, repel each other, and try to get farther and farther apart, while those of a liquid cling to each other. In order to hold a gas, you must close it in on all sides, as in a gas-bag or balloon, but a liquid will rest in a bucket without any lid over it. The molecules of a liquid, however, can easily glide by one another, and that is the reason a liquid will flow. When a liquid changes to a solid, the molecules cannot pass each other, and so a solid will hold its shape.

Water.—Water is the most abundant and the most important of all liquids, as air is the most abundant and most important of all gases. More than three-fourths of the whole surface of the earth's crust is covered with water, and the bottom, at some places, of the ocean is as far below the surface as the mountain-peaks are above it. Water runs through numerous channels in the ground and layers of rock. A great quantity of it, millions of tons, is in the air in the form of vapor. Even our own bodies are nearly three-fourths water. Water is present on all sides, and is our best example of a liquid. In this chapter we give a few experiments and state a few principles in regard to the action of water and other liquids.

Pressure in liquids.—A cubic foot of water weighs 773 times as much as a cubic foot of air at sea-level. The weight of a cubic foot of water is 62.42 pounds. When one cubic foot of it is placed on the top of another, the pressure at the bottom is twice 62.42, or 124.84 pounds on the square foot. At the bottom of the four cubic feet, as shown in the cut, the pressure is 249.68 pounds on a square foot. So we see that the deeper the water is, the greater will be the pressure on the square foot or the square inch. In the deep ocean the pressure is very great. At some points the ocean is five miles deep. If you will reduce this to feet and multiply by 62.42, you will have the pressure on every square foot at that depth. If you will then divide this number by 144, you will get the pressure on a square inch at that depth.

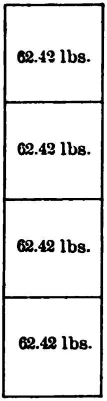

FIG. 35.—A column of four cubic feet of water. The pressure on the bottom is the sum of the weights of the cubes.

The pressure at any point in a liquid is equal in all directions, — upward, downward, or sideways. If this were not so, the water at that point would move.

So we have these two important laws, that the pressure increases with the depth of a liquid, and at any point the pressure is equal in all directions. These laws are also true for air, and for all liquids and gases.

A diver cannot go very deep into the water, for the water presses upon his body from all directions with such force that it would crush him if he continued to go on down.

Water seeks its own level.—Since the pressure increases with the depth, then, of course, if the depth is greater at one place than it is at another, the water will flow to the place where the depth is least until the surface is on a level.

Experiment 19.—Fit a cork into the larger end of a straight lamp-chimney. From two holes in the cork let glass tubes pass out, as shown in Fig. 36. Pour water into the chimney, and it will flow out into the tubes and come to the same level in the chimney and in the two arms. The distance from the surface of the liquid straight down to the lowest point

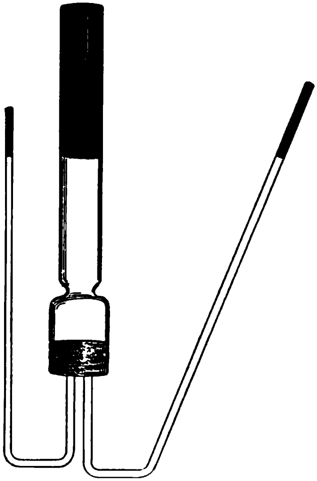

FIG. 36.—Water-level.

in the small tubes is the same on either side as in the chimney. We see from this that the depth, and not the amount, of water causes the pressure.

The fact that water will come to a level in all the vessels which are connected by pipes, is often made use of in supplying water to a town or city. A tall stand-pipe is built at the water-works, and pipes lead from it to the houses in town. Water is pumped into the stand-pipe till its surface is as high as the highest building. Then water will run from any faucet which is lower than the surface in the stand-pipe.

Artesian wells are caused by water seeking to come to a level. In some localities the sides and bottoms of a wide valley contain layers of clay with a layer of sand and gravel

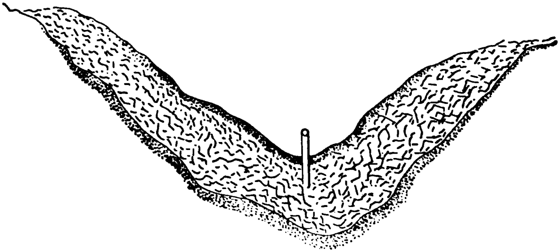

FIG. 37.—Plan of an artesian well.

between them, as shown in Fig. 37. Water cannot pass through the clay, but may filter in between the layers even at a distance of several miles up on a hill or mountain. Thus the water may be stored in large quantities and piled up to a great height. If, then, a hole be bored through the upper layer of clay at the bottom of the valley, the water will spout up, and will continue to flow as long as water continues to filter in at the top of the mountain.

Buoyancy.—If a block of wood be pushed down under water and then left to itself, it will quickly rise to the surface. This tendency of water to raise bodies to its surface is called buoyancy. This is caused by the fact that pressure increases with the depth. The bottom of the block is deeper in the water than the top, and so the pressure upward on the bottom is greater than that downward on the top. This difference in pressure is great enough to push a wooden block to the surface of the water. All bodies are buoyed up and,

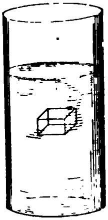

FIG. 38.—A body immersed in a liquid is buoyed up by a force equal to the weight of the liquid displaced.

under water, appear to be lighter than they are. But some, as iron, are so heavy that the buoyancy is not equal to their weight, and so they sink. A balloon rises because of the buoyancy of the air, and, as we have already seen, the cause for the rise of a balloon is just the same as that for the rise of a block of wood in water.

The weight of a man's body is just about equal to the buoyancy of the water when his body is all under the water. It is easier for one to float if he will lie on his back with only the nose out, for then nearly all the body is submerged and the buoyancy is greater.

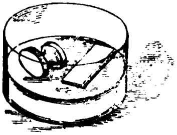

FIG. 39.—Iron and brass floating on mercury.

The heavier a liquid is the greater its buoyancy will be, because the difference of pressure is then greater for different depths. In Fig. 39, pieces of solid iron and brass are seen floating on mercury.

Experiment 20.—The object in this experiment is to find out how much a body is buoyed up when it is immersed in water. For this purpose there will be needed a spring-balance that is fairly sensitive, something like the one shown in Fig. 40, which will weigh objects up to eight ounces. A can should be provided which will hold about a pint or more and has a spout on one side near the top. A small bucket will be needed to catch the water that flows from the spout. Now fill the can till water runs from the spout. Weigh the small bucket carefully, and write this number on a slip of paper. Now fasten a small stone by means of a string to the hook of the balance. Note its weight and make a record of it. Then lower the scales so that the stone is immersed in the water in the can, and record its weight in that position. When the stone was placed in the water, of course the surface of the water was raised and some

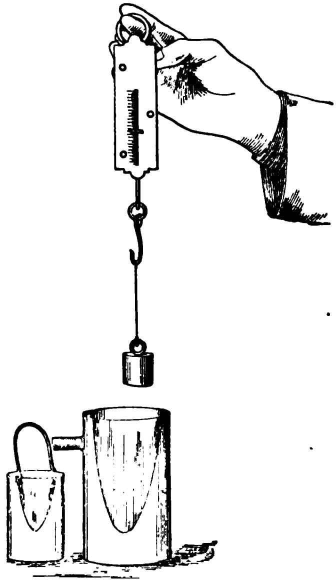

FIG. 40.—Buoyancy of water.

of it ran out into the small bucket. Now weigh the bucket with the water it contains, and from this weight subtract the weight of the bucket. The remainder will be the weight of the water which the stone caused to overflow. The difference between the weight of the stone *out* of the water and *in* the water will be found to just equal the weight of the water in the small bucket. For example, if the stone weighed six ounces out of the water and four ounces in it, the water which flowed out of the spout would weigh two ounces. Now when the stone was let down into the water it took the room of a volume of water just equal to its own volume. So we see that the stone was buoyed up by as much as the weight of a volume of water just equal to the volume of the stone.

Some thoughts on the experiment.— The experiment just described is very important, and when it is clearly understood, a number of common things are at the same time made plain. Why does iron sink in water? Because it does not displace enough water to equal its own weight. Why does a cork float on water? Because it has displaced enough water to equal its own weight when it has sunk only a short distance in the water. Why does an iron vessel float? Because the iron is in such a shape that it may sink into the water and displace its own weight of the water before any flows over into the vessel. When the vessel is once filled with water, it will sink like any piece of solid iron. Why does the piece of solid iron and brass float on mercury as shown in Fig. 39? Because the mercury is so heavy that iron and brass will displace their own weight of it by sinking only a little more than half-way. Why does a balloon ascend? Because the air displaced weighs more than the balloon, and bodies are always buoyed up by a force equal to the weight of the gas or liquid which they displace.

Specific gravity.—Specific gravity is the number of times any substance is heavier than the same volume of water. If a certain vessel full of water weighs one pound, and the same volume of mercury weighs 13.6 pounds, then the specific gravity of mercury is 13.6, which means that mercury is 13.6 times as heavy as water. All that is needed to find the specific gravity of any substance is to find the weight of some of it, no matter how much, and then find the weight of the same volume of water, and divide the weight of the substance by the weight of the water. Experiment 20 suggests an easy way to do this, for we can get the weight of an equal volume of water by simply weighing a body out of the water and then in it, and take the difference.

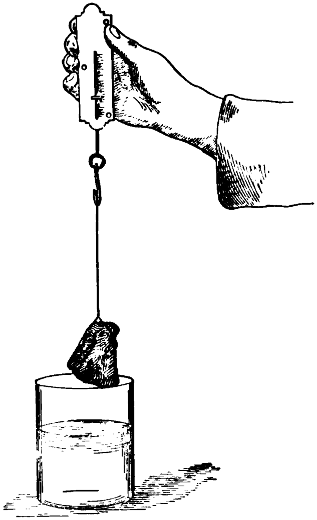
FIG. 41.—Finding the specific gravity of a brick.

Experiment 21.—To find the specific gravity of a brick. Break an ordinary brick, and suspend a piece of it from the hook of a balance with a thread. Record its weight, then suspend it in water and record its weight there. The difference in these two weights will be the weight of a volume of water equal to the piece of brick. Divide the weight of the brick by the weight of the water, and the answer will be the specific gravity. In the experiment illustrated in Fig. 41 the piece of brick weighed twelve ounces. When immersed in water it weighed seven ounces. Then the weight of a volume of water equal to the volume of the piece of brick must be five ounces. So $12 \div 5 = 2.4$, which is the specific gravity. Try this with pieces of stone, iron, or other substances. If a good balance like that shown in Fig. 42 can be had for these experiments, the results will be much more accurate.

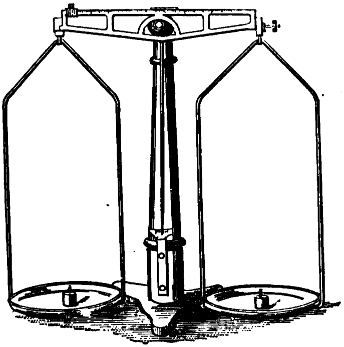

FIG. 42.—The balance.

Experiment 22.—To find the specific gravity of mercury. There are many different ways of finding the specific gravity of solids, liquids, and gases, but the principle is the same in all of them. We give here an easy way of finding the specific gravity of mercury.

Bend a glass tube into the form of a *U*, as shown in Fig. 43. Each arm should be about twelve inches in length. Pour mercury into the tube until it is about two inches high in each arm. Then pour water into one of the arms, say *a*, *b*, until the mercury at *c* stands just one-half inch higher than at *a*. Now measure the height of the column of water, and it will be found to be 6.8 inches high. This means that one-half inch of mercury will balance 6.8 inches of water. 6.8 is 13.6 times one-half, so the specific gravity of mercury must be 13.6.

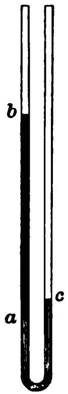

FIG. 43.—Finding the specific gravity of mercury.

The column of water in the figure looks black because it was colored with a drop of ink to make it visible.

QUESTIONS.

1. How do liquids differ from gases?

2. What is the weight of a cubic foot of water?

3. What is the pressure per square foot at a depth of 100 feet in water? How much would that be on every square inch?

4. Explain the cause of artesian wells.

5. What is the cause of buoyancy?

6. Why will not iron float on water?

7. Why will iron float on mercury?

8. Describe an experiment which shows how much a body is buoyed up when it is immersed in water.

9. Why does iron sink in water?

10. Why does a cork float in water?

11. What is specific gravity?

12. Explain how you would proceed to find the specific gravity of brick.

13. Explain a method of finding the specific gravity of mercury.

14. A piece of stone weighs just one pound, but when immersed in water it weighs only twelve ounces. What is its specific gravity?

CHAPTER IV

GRAVITY AND WEIGHT

Gravity.—Gravity is the name of the force which the earth exerts on all kinds of matter. All objects are drawn by it towards the centre of the earth. It is the cause of all weight and all the pressure in liquids and gases which we have described.

If plumb-bobs be suspended at any place, they will point directly towards the centre of the earth, and the line along the string is called *the line of direction.*

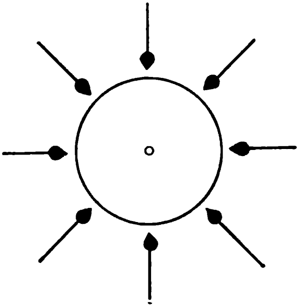

FIG. 44.—**Plumb-bobs pointing to the centre of the earth.**

It is plain from Fig. 44 that when two plumb-lines are some distance apart they will not be nearly parallel to each other, but will be farther apart at the top than they are down close to the bob. Carpenters and masons make use of plumb lines to make the walls of buildings straight up and down. The top of the walls of such a building would be a little farther apart than at the bottom, and so the top floor would be a little larger than the bottom one. In a small building this would not be noticeable; but if a building were 500 feet long and 500 feet high, then the end walls would be about .14 of an inch farther apart at the top than at the bottom.

Centre of gravity.—The centre of gravity of any body is a point on which the body will just balance itself, no matter in what position it may be placed. A plumb-line through this centre is its line of direction.

Experiment 23.—To find the centre of gravity of a potato. Press a carpet-tack into a potato and suspend it from a thread. The thread will give the line of direction through the centre of gravity. Hold the potato carefully in the position it hangs and press a long needle through it close to the tack and in line with the thread. The needle will pass through the centre of gravity. Now leave the needle in place and press the tack into the potato at some other point. Push another needle through at that point. If the experiment is carefully done, the second needle will strike the first one. Since the centre of gravity of the potato is somewhere in the path of both needles, it must be at the point where they meet. If the potato be hung from any part of it, the line of direction will pass through this point.

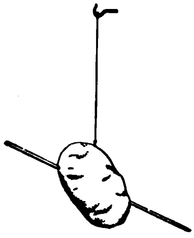

FIG. 45.—Finding the centre of gravity of a potato.

Experiment 24.—To find the centre of gravity of a board. Take a smooth board of any shape having an area of about one square foot. Drill holes through two or more of its corners. Suspend the board from a small round nail so that it hangs free. Suspend a bullet on a fine thread from the same nail in the manner shown in Fig. 46. The thread tells the line of direction in which the centre of gravity of the board must lie. With a pencil make a line on the board directly under the thread. Now lift the board off and hang it from another corner. Mark the line of direction again. These two lines will cross at a point directly over the centre of gravity of the board. The exact centre of gravity is in the wood directly under the point we have just found and half-way through the board.

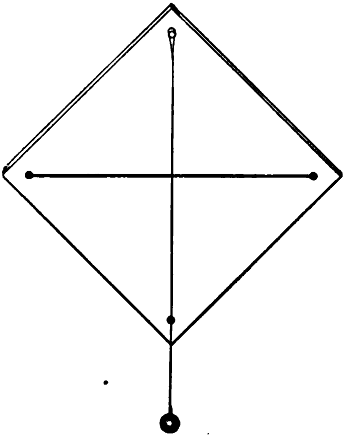

FIG. 46.—Centre of gravity of a board.

Equilibrium.—When a body is at rest in any position, it is said to be in *equilibrium*—that is, it is balanced between the forces which are acting upon it, otherwise it would move.

There are three kinds of equilibrium—*stable*, *unstable*, and *neutral*. A body is in stable equilibrium when it requires considerable force to upset it or push it over. It is unstable when a very slight force may push it over. It is neutral when a slight force will neither raise nor lower its centre of gravity. In Fig. 47 the two upper bodies are stable; the two middle ones, unstable; and the two lower ones, neutral.

A body will stand whenever the line of direction falls within the base upon which it rests. The first block in Fig. 48 has a large base, and the line of direction falls in the centre of it, so its position is stable. The second one is pushed over so that its line of direction falls at the edge of the base. It is now in an unstable position, and the least force will push it over. In the third, the line of direction falls outside the base, and so it must

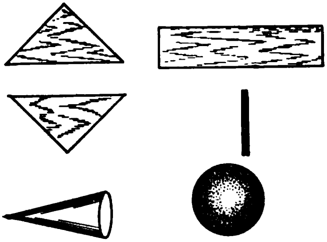

FIG. 47.—Three kinds of equilibrium.

fall over on its side. This is true of all bodies of matter. Our own bodies are no exception. Our base of support is our feet and the space between them. Whenever the line of direction through the centre of gravity of our bodies falls outside of this base, we are sure to fall.

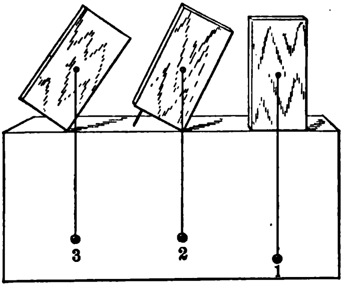

FIG. 48.—Conditions of stable equilibrium.

Why are we apt to fall when we stumble?

The lower the centre of gravity is the more stable the body will be.

This is why the base of many instruments is made of iron or lead. It is then more difficult to make the line of direction fall outside the base, and so they are not easily upset.

Experiment 25.—It is difficult to balance a pencil in an upright position because the centre of gravity is so high and the base of support so small. Thrust the blade of a penknife into each side of the pencil and support the tip of the pencil on the end of the finger, as in Fig. 49. The centre of gravity of the knives and pencil together is lower than the point of the pencil, and so they are in stable equilibrium. By similar explanation show how the horse in Fig. 50 can be in equilibrium though supported only on his front feet.

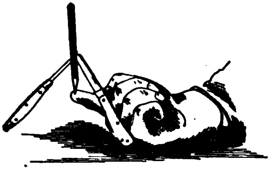

FIG. 49.—Stable equilibrium.

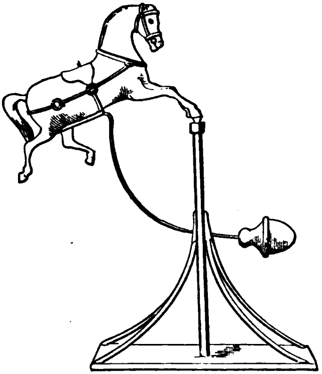

FIG. 50.—Toy horse supported only on front feet.

Weight.—The *weight* of any body is the force with which gravity acts upon it. The weight is not in the body itself, but is a force outside which pulls upon all objects near the surface of the earth.

The *mass* of a body is the amount of matter which it contains. The mass of any given body will always remain the same, no matter where the body may be placed, but the weight will change whenever the force of gravity changes. If you would carry a sack of sugar with you to the top of a very high mountain, you would have just as much sugar there as you had when you started, that is, the mass would remain the same; but the force of gravity grows less as you leave the earth, and so the weight of the sugar would be a little less.

We live and do nearly all our work on the surface of the land and water, and so we are always at nearly the same distance from the centre of the earth. For this reason we take the weight of anything as nearly an exact measure of its mass. When you ask the grocer for a pound of sugar, he puts sugar on the scales until he sees that gravity pulls down upon it with a force of one pound. If you then decide that you want two pounds, he continues to add sugar until gravity pulls with a force of two pounds, and then he knows that he has twice the mass of sugar. The weight is a convenient way of telling how much matter there is in a body.

Falling bodies.—The force of gravity tends to pull all objects down to the lowest points on the earth. That is why the rain falls and the rivers run down hill. That is the cause of land-slides and snow-slides, and so on.

The pull of gravity is exactly the same on all equal masses. Let the small squares in the upper row (Fig. 51) represent equal cubes of iron, then gravity will pull with the same force on each one; and if they are all let fall they will fall together and will reach the ground at the same time.

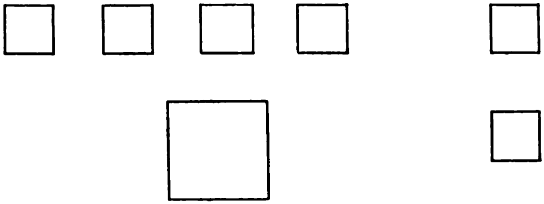

FIG. 51.—Representing falling cubes of iron.

If four of the cubes be melted and cast into one larger cube, it will contain a mass four times as great as the small one, and so gravity will pull down upon it four times as hard. So we would expect the large and the small one to fall together and reach the ground at the same time.

Experiment 26.—Select two stones of the same kind, one about as large as a marble, and the other about ten times as large. Carry them to an upper window of a tall building and place them side by side upon a piece of board. Have some one on the ground beneath the window to observe whether or not the stones reach the ground at the same time. Now lift the board and hold it out beyond the window-sill. Turn the board over so that both stones start at the same time. They should reach the ground together.

Several sets of stones or other kinds of matter should be taken up at the same time so that several trials may be made.

Gravity on the moon.—There is eighty times as much matter in the earth as there is in the moon. For this reason the force of gravity on the earth is much greater than on the moon. If a boy weighs eighty pounds on the earth, he would weigh only about thirteen pounds if he could be transported to the moon. If he is a good jumper, he could jump straight up a distance of thirty feet, and he would then fall back to the ground with no more harm to himself than when he falls a distance of five feet on the earth. If he could lift a weight of one hundred pounds on the earth, he would there be able to lift more than a quarter of a ton.

Gravity on the sun.—The sun is a very large body. Our earth is nearly 8000 miles in diameter, but the sun is nearly 860,000 miles in diameter. The distance through the sun is more than one hundred times the diameter of the earth. If a boy weighing eighty pounds could be transferred to the surface of the sun he would weigh over 1800 pounds. He could not stand, for his own weight would crush him to the ground. He could not even raise his arm because of its great weight.

QUESTIONS.

1. What is the direction of a plumb-line?

2. Where is the centre of gravity of any body?

3. Describe a method of finding the centre of gravity of a potato. Of a board.

4. What are the three kinds of equilibrium? Illustrate each kind.

5. When will a body fall over?

6. Why are inkstands made with broad heavy bases?

7. Why are you liable to fall when you walk on ice?

8. Explain how you can hold a pencil upright on the tip of your finger.

9. What causes bodies to have weight?

10. What is meant by the mass of a body?

11. How do we determine the mass of objects?

12. If a small and a large piece of iron be let fall from an upper window, which will reach the ground first? Explain why this is so.

13. What is the force of gravity on the moon?

14. What is the force of gravity on the sun?

CHAPTER V

THE PENDULUM

Use of the pendulum.—The pendulum is the best instrument we have for keeping accurate time. It has been used for that purpose since the latter part of the 16th century, A.D. Before that time they used sun-dials, hour-glasses, and many other contrivances, but none of them were as accurate and convenient as the pendulum clocks which we have to-day. A simple pendulum consists of a heavy bob suspended by a fine wire or string; but any body of matter, such as a board or bar of metal, may be suspended at one end or corner and be made to swing back and forth as a pendulum.

What makes the pendulum swing?—When a ball of iron or lead is suspended by a very fine string, the centre of gravity will be very nearly at the centre of the ball. The string is so light that it may not be counted in the weight of the pendulum. Now, we have learned that gravity is trying all the time to draw bodies down to the lowest possible position. When the bob of a pendulum is pulled to one side, its centre of gravity is raised. In Fig. 52, if the bob is moved from *A* to *B*, it will be raised as much as the distance between the horizontal lines. If, when the bob is at *B*, it is set free, gravity will cause it to fall to the lowest possible position. The string is holding it so that it cannot fall straight down, but it can swing from *B* back to *A*,—the lowest point it can find. When the bob reaches *A*, it is going so fast that it does not stop there, but swings to the other side. Gravity then pulls it back again, and so it continues to swing from side to side.

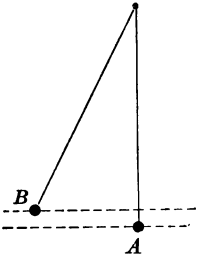

FIG. 52.—The pendulum a falling body.

Every time the bob swings it is slowed up a little by the resistance of the air, and in time it will come to rest at *A*. If it would meet no resistance, it would swing back and forth forever.

In a clock there is a light arm which reaches down and gives the pendulum a slight push on one side and then on the other. The arm is operated by the weights or spring which we wind up. Thus the pendulum will continue to swing as long as the clock is wound up, and the speed of the hands on the clock will be regulated by a system of wheels which are controlled by the pendulum.

The first law of the pendulum.—A pendulum will swing in the same time whether it swings through a short or a long distance.

Experiment 27.—Fasten a lead bullet to the end of a very fine silk or cotton thread. The thread may be about two or three feet long. Cut a slight gash in the bullet and close the cut upon one end of the thread. Now suspend the bullet in some convenient place where it can freely swing. Set the pendulum swinging through a short distance, not more than three or four inches from one side to the other. Take in your hand a watch and, by observing the second hand, count the number of swings made by the pendulum in one minute. Each time the bob moves from one side to the other is one swing. Try it several times to make sure that you are right. Write the number on a slip of paper.

Now cause the pendulum to swing through a greater distance, say ten or twelve inches,

FIG. 53.—Chandelier observed by Galileo. The chain from which the chandelier hangs is not shown in the figure.

and carefully count again the number of swings in one minute. There will be the same number of swings in both cases. This shows that a pendulum will swing in the same time whether it moves through a short or a longer distance.

It was this fact that suggested the use of the pendulum in clocks. In the year 1583 Galileo was sitting in the cathedral of Pisa. He was then but nineteen years of age, but he was a close observer. He noticed that the chandelier was swinging, and that it swung in the same time through a short or a longer distance. This led him to investigate the laws of the pendulum and suggest its use in clocks. In Fig. 53 is shown this famous old chandelier as it is now pointed out to travellers who visit the old cathedral.

The second law of the pendulum.—A pendulum will swing in the same time, no matter whether the bob is light or heavy.

Experiment 28.—Suspend a bullet from a thread as explained in the previous experiment, and count the exact number of swings it will make in one minute. Then attach another bullet so that the two will hang side by side. Be careful not to change the length of the pendulum. You will now have a bob of double the weight. Cause it to swing, and again count the number of swings in one minute. The number will be the same whether the bob consists of one or two bullets.

The third law of the pendulum.—The longer a pendulum is, the slower it will swing, and the shorter it is, the faster it will swing.

Experiment 29.—Prepare two pendulums like the ones described above and hang them near each other from a solid support. Make one of them 36 inches long. To get its length measure from the nail to which it is attached down to the centre of the bob. Make this measurement with care. You may at first think that, if the other pendulum is half as long, it would swing twice as fast; but is this so? Try it. Make the second pendulum 18 inches long, and set both in motion. By counting the number of swings of each for one minute you will soon see that the shorter pendulum does not swing nearly twice as often as the longer one. Then make the shorter one just 9 inches long, and carefully count again for one minute or more, and it will be found that every time the long pendulum swings once, the short one will swing twice. The lengths are as 9 to 36, and we have found that the number of swings are as 6 to 3. The square root of 36 is 6, and of 9 is 3. So we may state this rule more exactly by saying that the number of vibrations of a pendulum will vary inversely as the square root of the length. *Inversely* means that the *longer* the pendulum is the *less* the number of swings, and the *shorter* the pendulum the *greater* the number. The number of swings do not vary as the length, but as the square root of the length. To make the short pendulum vibrate three times as fast, it must be $\frac{1}{9}$ as long, and if four times as fast, $\frac{1}{16}$ as long, and so on.

Experiment 30.—To determine the length of a seconds pendulum. A pendulum that will swing from one side to the other in one second is called a seconds pendulum. To find its length, suspend a ball weighing four or five ounces by a very fine thread. Pass the upper end of the thread through a gash made by a sharp knife in the end of a board. Fasten the end of the thread by wrapping it a few times about a tack, or by placing a weight upon it. This arrangement makes it convenient to change the length of the thread, and also to measure the length of the pendulum. The length will be the distance from the under side of the board down to the centre of the ball. Begin with the pendulum 36 inches long. A seconds pendulum must swing 60 times in one minute. Set the pendulum going. Count the swings, and also keep an eye on the second-hand of your watch. You will soon see that the pendulum is going too fast for a seconds pendulum. Stop it, and let the thread slip down a little so as to make a pendulum 39 inches long. Now count again, and it will appear at the end of one minute—60 seconds—that the pendulum has made 60 swings. Continue to count for five minutes, and if the pendulum seems to still swing a little too fast, make it just a trifle longer and count for five or six minutes again. If at the end of five minutes—300 seconds—you have counted just 300 swings, then you have a seconds pen-

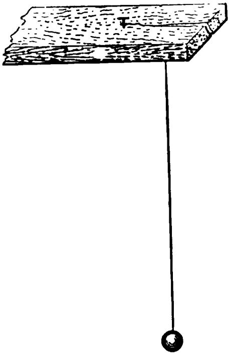

FIG. 54.—Support for pendulum.

dulum. Measure it carefully. In the United States the length of such a pendulum is very nearly 39.2 inches.

How to regulate a clock.—Not many clocks have seconds pendulums. You cannot tell the number of seconds by counting the ticks of a clock, unless the pendulum is 39.2 inches long. The clock which I hear while I write this, ticks 120 times in one minute, so the pendulum must swing twice every second. Count the ticks of your home clock and determine how many times its pendulum must swing in a minute. A clock which ticks many times in a minute may keep just as good time as one which ticks but few times, but the arrangement of the wheels is different, so that the hands are made to turn at the same rate of speed.

The important thing is to know how to regulate any clock so that it will keep the same time from day to day.

We have learned from the experiments that we cannot make a pendulum move any faster or slower by changing the weight of the bob.

We have also learned that a pendulum

swings in the same time whether it moves through a long or a short distance.

The only way, then, to change the time of a clock is to change the length of the pendulum. This is what is always done. A small set-screw at the bottom of the pendulum enables you to raise or lower the bob. If your clock is running too fast, you must lengthen the pendulum by letting the bob down. If too slow, shorten the pendulum by raising the bob.

Examine your clock at home, and see what provision is made for changing the length of the pendulum.

A very small change in the length of the pendulum will make considerable change in the time after a week or month has passed.

QUESTIONS.

1. When did the pendulum begin to be used for keeping time?
2. State the first law of the pendulum.
3. Describe the experiment which will prove the first law.
4. Tell about Galileo.
5. State the second law of the pendulum.
6. Describe the experiment which will prove the second law.

7. State the third law of the pendulum.

8. Describe an experiment to prove the third law.

9. How can you determine the length of a seconds pendulum?

10. How many times does your home clock tick in one second?

11. How can you change the pendulum of a clock so that it will run faster or slower?

12. Why are most pendulum bobs made flat?

CHAPTER VI

CURVILINEAR MOTION

A law of motion.—When a body is once in motion, it will continue the motion in a *straight line*, unless some outside force interferes.

If any body is found to be moving around in a circle or any kind of a curve, you can be sure that there is some force acting upon it to push or pull it out of a straight line. This is true because of the inertia of all matter as was explained in Chapter I.

Experiment 31.—Fasten a stout thread to a lead bullet or small piece of iron. Hold to the end of the string and swing the bullet, causing it to revolve rapidly about the hand. Notice that the hand must pull constantly on the string to keep the bullet going in a circle. If the string should break, the bullet will go off in a straight line. That is the course the bullet wants to move in all the time, but the string constantly pulls it out of its course.

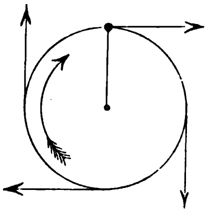

FIG. 55.—A moving body, if let alone, will move in a straight line.

Swing the bullet around in the direction of the arrow as shown in Fig. 55, and when it reaches the lowest point of the circle, let the string go. It will move straight off to your left. Try this several times till you can let go at the proper time. Now let go when the bullet is at the top of the circle, and it will move straight off to the right. At the right of the circle it will move straight downward, and at the left, upward. The bullet does not pull out on the string. All it wants to do is to go right on in a straight line.

Some examples of motion in a curved line.—When one is running and desires to make a sudden change in his direction, as in turning a sharp corner, a strong effort must be made to keep the body from going on in a straight line. If the ground is icy, there is great danger of a fall.

When a circus performer rides rapidly around the ring on the back of a horse, he leans in towards the centre of the ring, so he can brace himself against the tendency to go on in a straight line and fall off the horse towards the outer side of the ring.

Every one has noticed the water flying off a grindstone when it is rapidly rotated. The tendency of the water to move in a straight line caused it to fly off.

In many of the good modern laundries the wet clothes are made nearly dry by placing them in a wire cylinder, or a metal cylinder filled with small holes, and then rapidly rotating it. The water is thrown from the clothes and out through the holes in the side of the cylinder, just as it is thrown from a rotating wheel of any kind. In this way the clothes can be made much drier than is possible with an ordinary clothes-wringer.

Experiment 32.—Fill a gallon bucket half full of water. Swing it rapidly around and around at full arm's length. When the bucket is at the top of the circle it will be upside-down, but the water will not fall out, because its tendency to go on in a straight line will keep it in the bucket as long as it is swung around. If you will make a small hole in the bottom of the bucket, then partly fill it with water and swing it rapidly around; you will find that water will spurt from the hole, whatever the position of the bucket. This will show that there is pressure upon the bottom of the bucket even when it is upsidedown.

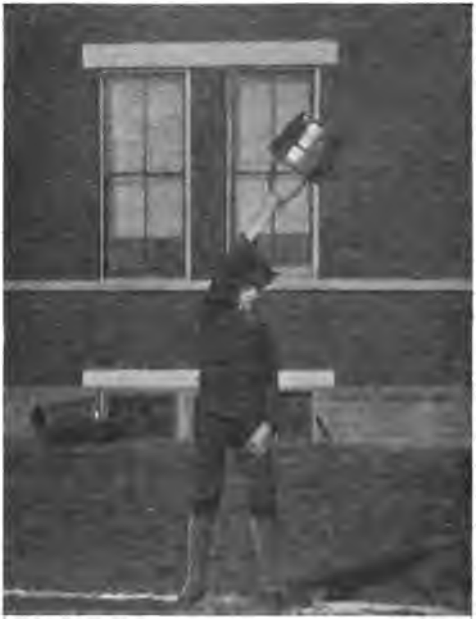

FIG. 56.—Bucket of water upsidedown.

The shape of the earth.—You have learned from a study of geography that the distance from the north to the south pole of the earth, as measured through the centre of the earth, is about twenty-six miles less than the distance through the earth from one side of the equator to the other. The earth is thus bulged out at the equator, and compressed or flattened at the poles. What is the cause of this? It is believed that at one time the earth was so hot that all the material which now forms the solid rock and all the metals was melted and in a liquid state. The earth was rotating then as it is now, and, being a liquid, it would readily take any shape that might be forced upon it.

Now, the part of the earth at or near the equator goes entirely around once every day, that is, it moves in a circle which is nearly 25,000 miles in circumference, and completes the trip in one day. This circle is marked *E.* in Fig. 57. The circle marked 40 is parallel to the equator but some distance north of it, say in latitude 40° north.

Any object on this circle will also go completely around once each day, but its circle is not nearly so great in circumferance, and so, of course, it will not need to go so fast to complete the trip in the same time. As we go closer and closer to the pole, the circles become smaller and smaller until, right at the pole, the circle becomes a point.

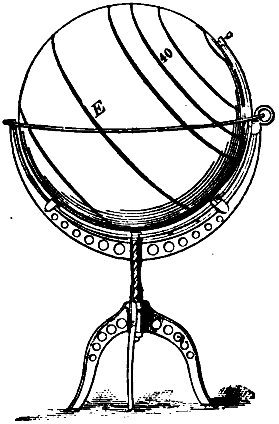

FIG. 57.—Rotation of the earth.

It is plain, then, that the part of the earth which is close to the equator must move much faster than those parts which are between the equator and the poles. As a result, there is a greater tendency to fly off at the equator, and that is what causes the earth to bulge out at that place and flatten at the poles.

This is also the reason that an object will weigh less at the equator than it will at any point near one of the poles. The difference amounts to $\frac{1}{289}$ of the body's weight. If a man at the north pole weighs 289 pounds, he would weigh 288 at the equator.

It can be proven that if the earth would rotate seventeen times in one day instead of once, as now, then an object at the equator would have no weight at all. Gravity would pull down just as much as before, but the tendency to fly off would be just as strong as gravity. If you were standing at the equator, then, and would jump up, you would never come back. Nothing would have any weight there, and you could hold a horse or a house on one hand at arm's length. Think of some other results that would follow such a peculiar condition.

Experiment 33.—To illustrate the effect of rotation. To do this, secure a strip of any thin elastic metal, about one-half inch wide and twenty-four inches long. Bend the strip in the form of a circle. Allow the ends to overlap about one inch and solder them together. Punch a hole through the centre of the parts

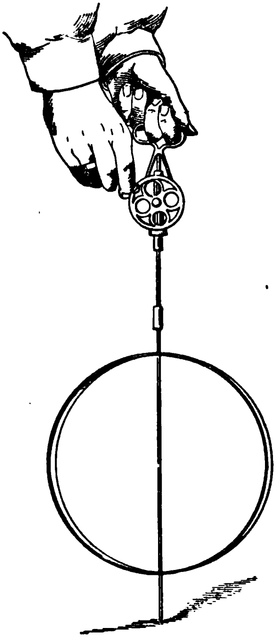

FIG. 58.—Rotating hoop.

that overlap, and another hole directly opposite at the top of the circle. Pass a straight, stiff wire through the holes, allowing it to project about two inches beyond the circle at each end. Solder the circle to the wire at the hole where the strip is lapped, but leave the top of the circle free to slide on the straight wire. It is then ready to be attached to the rotator shown in Fig. 59.

The circle must now be rapidly rotated. This may be done by means of the rotator shown in the figure. It is a simple form of egg-beater, which may be purchased in any town. By heating the solder at the end of it, the fans may be pulled off, leaving a straight central wire which rotates when the cog-wheel is turned. By means of a double-connector or other device, attachment may readily be made to the central wire of the ring.

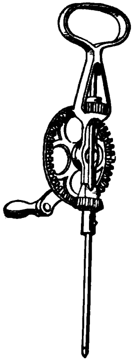

FIG. 59.—The rotator.

When the ring is by this means rapidly rotated, it will bulge out at the equator and flatten at the poles. Since the ring is loose at but one pole, all the movement will be there.

This rotator, made from the egg-beater, will be found very useful in a number of other experiments.

Rotation on the short axis.—An axis of rotation is the line around which a body rotates. The axis of rotation of the earth is a line from the north to the south pole. The axis of rotation of the wheel of a wagon is a line through the centre of the hub and lengthwise of the hub. When a piece of board or slate is made to rotate edgewise, it is then rotating on its shortest axis, because the axis is, in that case, only its thickness.

When a body is rapidly rotating on its shortest axis, it will strongly hold itself in that position. It can easily be moved edgewise or sidewise, but it cannot easily be twisted to one side or the other, as can be shown by the following experiment.

Experiment 34.—Get a bicycle-wheel at a repair shop, or take one from your bicycle. The shortest axis about which it can be rotated is the spindle through the hub. Support the wheel by placing the first finger of the left hand under one end of the projecting spindle. With the right hand give the wheel a rapid rotation, and it will remain in a vertical position, as shown in Fig. 60, although supported on but one side. When the motion becomes slow, the wheel will fall.

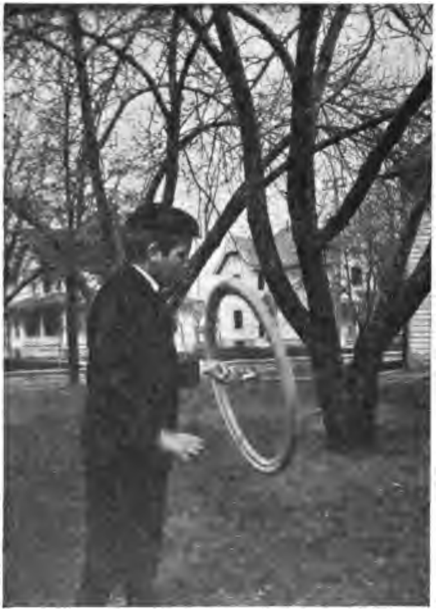

FIG. 60.—Rotating wheel supported only at one end of axis.

Again rotate the wheel rapidly, and hold both ends of the spindle, one in each hand, and, by pushing with one hand and pulling with the other, try to twist the wheel out of its position. It will be found that the rotating wheel will strongly resist this attempt.

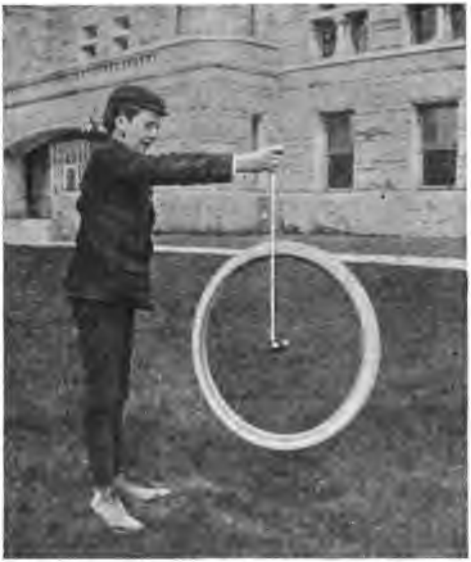

FIG. 61.—Bicycle-wheel supported by a string from one end of axis.

As shown in Fig. 61, the wheel may be supported by a string tied to one end of the spindle, and, although it may be swung from side to side or carried about, it will always hold its position, that is, it will not twist from one side to the other.

Some thoughts on the experiment.—The principles illustrated in the experiments are useful in many ways. The earth is rotating from west to east on its shortest axis. For this reason it holds its position permanently and there is no danger that we may wake some morning and find the sun rising in the north or south.

The hoop which a boy rolls along on the pavement is rotating on its shortest axis, and so it will not fall over as long as it is made to rotate.

The rapid rotation of the wheels of a bicycle assist the rider in keeping an upright position. That is why it is much easier to balance one's self when riding rapidly than when riding slowly.

A slater on the top of a house may wish to throw a piece of slate to the ground without breaking it. To accomplish this, he will want the slate to strike the ground edgewise. So he holds the piece of slate in the position he wants it to strike and rapidly rotates it just as it leaves his hands. Since it is rotating on its shortest axis, it will hold that position all the way down, and will be sure to strike on its edge.

Many examples of this kind might be given.

Experiment 35.—Use again the rotator which you made from the .egg-beater. By means of a cord, suspend from it a piece of board as shown in Fig. 62. Turn the rotator, and the board will gradually rise and rotate in a horizontal position. It is then rotating on its shortest axis. Lift off the board and try a ring or a loop of a chain. They will act in the same way. Try other bodies of various shapes.

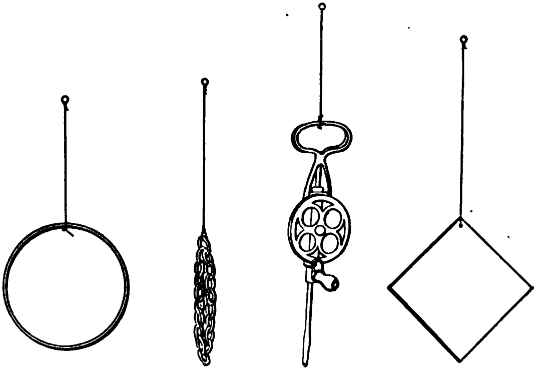

FIG. 62.—Ring, chain, and board for suspension from the rotator.

The explanation of this tendency to rotate on the shortest axis is that all matter when in motion tries to move in a straight line, and it can come nearer to doing this when it rotates on its shortest axis than on any other axis.

QUESTIONS.

1. State a law of motion.

2. Give some examples of motion in a curved line.

3. How can water be made to remain in a bucket when the bucket is upsidedown?

4. Why is the earth flattened at the poles and bulged at the equator?

5. How much less does an object weigh at the equator than at the poles as a result of the earth's rotation?

6. How can the effect of rotation be illustrated by a hoop of iron or brass?.

7. On what axis do bodies tend to rotate?

8. Describe the experiment with the wheel of a bicycle.

9. How can you throw a piece of slate, or other flat body, so that it will be sure to strike the ground on its edge?

10. Why does a boy's hoop stand up while he makes it roll along the pavement?

CHAPTER VII

MACHINES

What is work?—Whenever a force produces motion, work is done. If you lift a bucket of water from the floor to the top of a table you do work, because you use force and move the bucket through a distance equal to the height of the table. If the bucket were twice as heavy, you would need to use twice the force, and so would do twice the work. If you would lift it through twice the distance, you would also do twice the work.

When you turn a grindstone or a coffee-mill, you are doing work. In all cases you do work whenever you make any body of matter move by applying force to it.

What is a machine?—A machine is any kind of a device by which work can be conveniently done. A machine never does any work of itself, but it is often very convenient to do work by means of a machine. For example, a handspike is a machine, and it is very convenient, often, to use it as a pry in lifting a weight, or in other work. The handspike alone would never do any work.

A derrick is a very useful machine, but it can do no work of itself. When a man at the bottom of the derrick turns a crank and winds up the rope, a heavy stone may be raised to the top of a building, but the man did all the work. The derrick is only a convenient device for raising the stone.

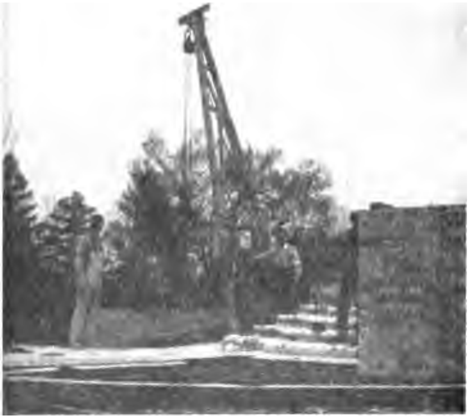

FIG. 63.—A derrick.

We have already defined energy as ability to do work. When a machine receives energy, it passes the energy on to the object upon which the work is being done ; but a machine must always receive energy before it can give any out.

The lever.—The lever is one of the most useful machines. It is used in a great variety of ways. Nearly all machines contain levers in some form. Most of the motions of our own bodies are made by levers of bone. There are three kinds of levers, known as levers of the *first class*, *second class*, and *third class*.

Levers of the first class.—In all levers there are three points to be considered. The point where the power is applied, the point where the weight is applied, and a point, called the *fulcrum*, where the lever is at rest. In a lever of the first class the fulcrum is between the power and the weight, so that whenever the power acts in one direction the weight will be moved in an opposite direction.

Experiment 36.—Prepare a stick of light wood about twelve inches long, one inch wide, and about one-quarter inch thick. Lay it by a ruler and mark upon it the inch, half-inch, and quarter-inch spaces. Find the exact centre of the stick and drill a hole through it near one edge. Suspend it on a small round nail through this hole, as shown in Fig. 64. The stick will then rest in a horizontal position. The fulcrum is at the nail, with the power, marked *P*, on one side, and the weight, marked *W*, on the other. This is a lever of the first class, which always has the fulcrum *between* the power and the weight. The distance from the power to the fulcrum is called the *power-arm*, and the distance from the weight to the fulcrum is called the *weight-arm*. It is a law of all levers that *the power multiplied by the power-arm is equal to the weight multiplied by the weight-arm.*

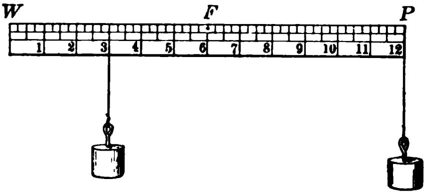

FIG. 64.—Lever of the first class.

Now hang a weight from one end of the

lever and an equal weight at the other end. The lever will still be balanced, because the weights are equal and their distances from the fulcrum are equal. The distances are six inches, and, if you used two-ounce weights, then 2 x 6 on one side is equal to 2 x 6 on the other.

Now slide the string which holds one of the weights along the stick to a mark three inches from the nail, leaving the other weight at the end, as in the figure. The lever will no longer be balanced. Double the weight which was moved, and there will be balance again. The weight at the end is half as great as the other, but it is twice as far from the nail, so that 6 x 2 is equal to 3 x 4. Try other distances from the nail and change the weights till the lever is balanced. Then see if one weight multiplied by its distance from the nail is in all cases equal to the other weight multiplied by its distance from the nail.

Some thoughts on the experiment.— One of the weights in the experiment may be considered as the power and the other as the weight which we may wish to raise. The experiment shows that whenever the power-arm is long, and the weight-arm is short, a small power will balance a large weight.

It may seem, at first, that this machine does some work. In Fig. 65 the man is pushing

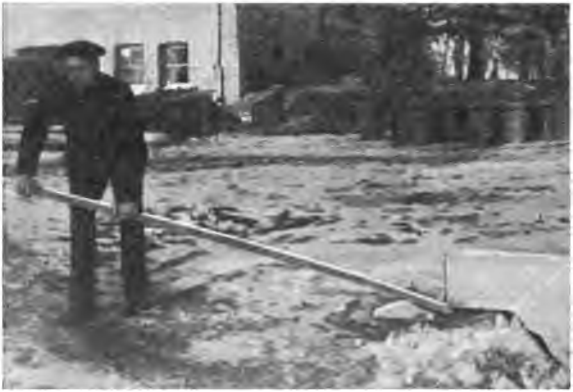

FIG. 65.—Use of the hand-spike.

down with a force of only 25 pounds, but the stone which he is raising weighs 250 pounds. But you must notice that the distance from the fulcrum to the man is ten feet, while the distance from the fulcrum to the stone is only one foot. The man will need to move his end of the lever down through a distance of five feet to raise the stone one-half a foot. So we see that although the man did not exert much power at any time, yet he had to take a longer time and move through a much greater distance. By the time he has raised the stone to where he wants it, he will have done just as much work as several men together would do in lifting the stone with their hands to the same height.

The lever, then, does not do any of the work; but it is a great convenience, and enables a man to do slowly a great deal of work which he could not do at all without the aid of a machine.

Levers of the second class.—The principle of levers explained above will be true of all levers, but in levers of the second class the three points are arranged differently.

The *fulcrum* is at one end, the *power* at the other, and the *weight* is between them.

Experiment 37.—Prepare a stick two feet long and suspend it from a nail at its centre as shown in Fig. 66. Only one end of it is to be considered as the lever. The purpose of the other end is to balance the lever so that the weight of the wood will not need to be considered. Mark off in inches, halves, and quarters the distance from the nail to one end of the stick and call this the total length of the lever. Pay no attention to the other half of the stick. The nail is then at one end of the lever. Support the other end by a thread from spring-scales, and call this the power. Hang a weight half-way between the power and the weight. In this arrangement the scales will show that the power is half as great as the weight. The power, however, is twelve inches from the fulcrum and the weight but six inches. So the power multiplied by its distance is equal to the weight by its distance.

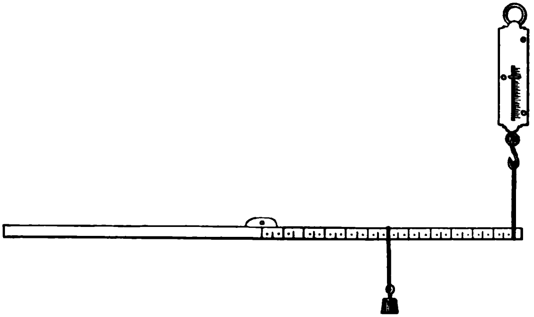

FIG. 66.—Lever of the second class.

Move the weight to different positions on the lever and test whether this law is true in all cases.

Examples of levers of the second class.—Levers of the second class are quite common. A wheel-barrow is a good example. As shown in Fig. 67, the fulcrum is the axis of the wheel, the power is applied at the end of the handles, and the weight is the load on the barrow. If the centre of the load is half-way from the centre of the wheel to the man's hands, then the man will have to lift with a force equal to half the weight of the load. The experiment shows that the nearer the load is to the wheel, the less the man will need to

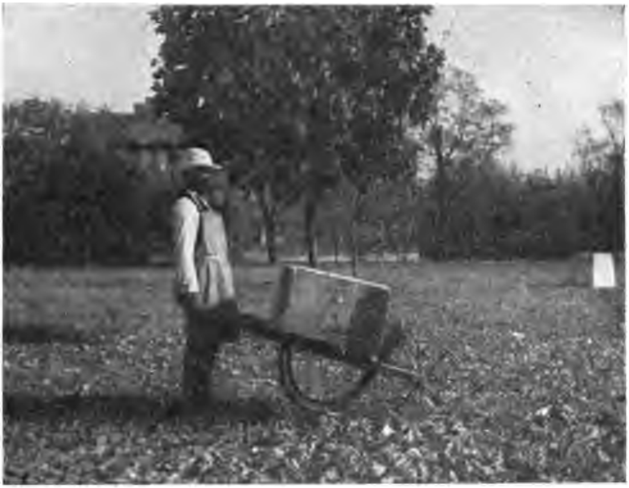

FIG. 67.—A lever of the second class.

lift, and the nearer the load is to his hands, the more he will need to lift.

Another good example is the lever at the top of a force-pump. As shown in Fig. 68,

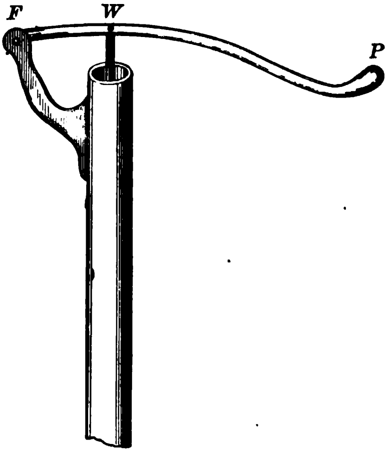

FIG. 68.—A lever of the second class.

the fulcrum is the end of the handle which is fastened with a bolt, the power is applied at the other end, and the rod of the plunger is fastened between them. The closer the rod is to the fulcrum the more powerful the lever, but the slower it will pump water. Try to think of other examples of this kind of lever.

Levers of the third class.—Levers of the third class have the *fulcrum* at one end, the *weight* at the other, and the *power* between them.

Experiment 38.—Use the wooden stick which was prepared for Experiment 37. Hang the weight at the end of the lever and attach the scales between it and the nail. In this arrangement, then, the power is between the weight and the fulcrum. If the power is half-way between, the scales will show that the power is twice as great as the weight. As the power is only six inches from the fulcrum, while the weight is twelve inches, the law still holds true for this lever that the power multiplied by its distance from the fulcrum equals the weight multiplied by its distance.

Some examples of levers of the third class.—Levers of the third class are not used in lifting heavy weights, because, as you can see in Fig. 69, the power will always be greater than the weight. But such a lever is very convenient when we wish to produce a rapid motion through a long distance. Grasp the lever (Fig. 69) two inches from the fulcrum between the thumb and finger. Move the hand up and down through a distance of two inches, and the end of the lever will be moved up and down through a distance of twelve

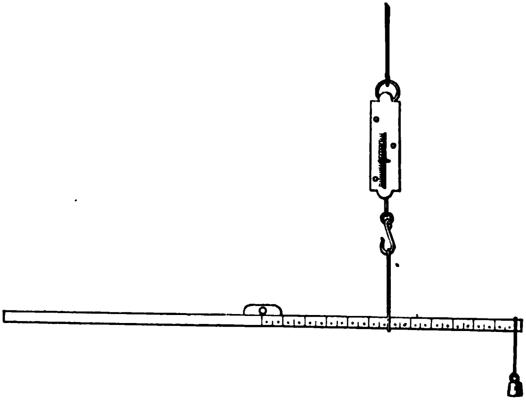

FIG. 69.—A lever of the third class.

inches. Try it when the hand is at various distances from the fulcrum.

A good example of a lever of this class is the forearm. Here the elbow is the fulcrum, the weight is in the hand, and the muscle which exerts the force is attached to the radius at a point between the hand and elbow, but closer to the elbow. It is plain from this that the forearm is not suited for lifting heavy weights, but it is well suited for giving the hand rapid motions.

This kind of leverage is in most cases used when a man handles a shovel or pitchfork.

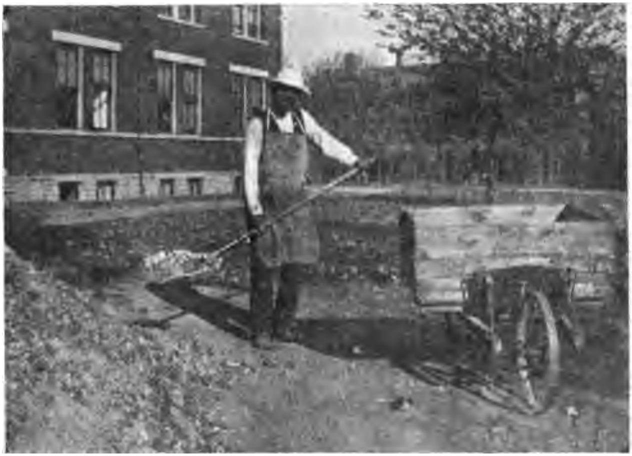

FIG. 70.—A lever of the third class.

In Fig. 70 the left hand grasps the end of the handle and makes it the fulcrum, or still place. The weight is on the shovel, and the right hand furnishes the power at a point between the other two. Such a shovel is also often used as a lever of the first class.

If you will notice how much the lever, of one kind or another, is used by men when they work, and how common it is in complex machines of various kinds, you will know how important the lever is.

The pulley.—A pulley is a wheel with a groove around its edge and an axle through its centre. It is mounted in a frame of some kind and can freely turn. It is, in fact, a lever of the first class with the fulcrum in the centre. If a great number of levers of this kind were put together so that their centres would all be at the same place, they could be made to form a wheel like that shown in Fig. 71. If this wheel were free to rotate around its centre, it could be used as a pulley. Any force pulling down on one side would raise the other side, just as pulling down on one end of the lever at the top of the figure would raise the other end. The advantage of the pulley over a single lever is that a new lever is constantly coming around as you rotate the pulley. Such a pulley may be considered a continuous lever of the first class.

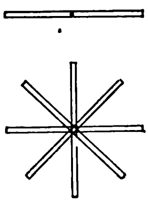
FIG. 71.—Levers of first class.

Experiment 39.—Secure a good pulley of some kind, such as is shown in Fig. 72, *A*, and fasten it to a support. In case such a pulley is not available, a spool on a smooth round nail will do fairly well (Fig. 72, *B*). Pass a thread over the pulley and fasten weights to its two ends. If one weight is lighter than the other, it will rise and the heavy one will fall. But if the two weights be made equal, they will balance on the pulley, because the distance from the centre of the pulley to the string is equal on both sides.

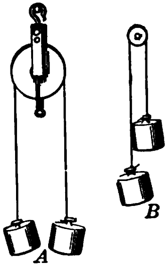

FIG. 72.—Pulleys.

When a pulley is arranged in this way it is called a *fixed pulley*. The advantage in its use is that a force exerted on a rope in one direction may be made to move a weight in a different direction. A fifty-pound force can raise only a fifty-pound weight; but a man may pull *down* at one end of a rope and *raise* a sack of wheat at the other end, provided the weight of the man is a little more than that of the sack of wheat.

Experiment 40.—Secure another pulley and arrange it, along with the fixed pulley, in the manner shown in Fig. 73. Two spools may be used, but it is better to use tape with them instead of the thread.

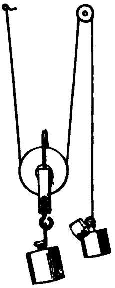

FIG. 73.—Movable pulley.

The lower pulley is called a *movable pulley* because it simply hangs on the thread and is not fastened to any support. The weight is hung from the movable pulley and is supported by two strands of the string. Each strand then holds up only half the weight. To test this, hang on the end of the string a weight which is half as heavy as the one which hangs from the movable pulley, and see if they will balance.

Now pull the end of the thread down through a distance of twelve inches and notice how much the movable pulley will be raised. It will be seen to rise only six inches. So, while you used a force only half as great as the weight, you were compelled to move the force through twice as great a distance.

Some thoughts on the experiments.—A pulley is a very useful machine. A number of movable pulleys are often fastened into the same frame, or block, as shown in Fig. 74. The same number of fixed pulleys are above. The cord is fastened to the frame of the fixed pulleys and passed around the first movable pulley, then up over the lower fixed one, then down under the second movable one, and so on. Any number of pulleys may be used. In the arrangement shown in the figure, the weight is hanging on six strands of the cord. It is plain that each cord must hold up one-sixth of the weight. If the hand pulls down with a force of one pound, it can raise a weight of six pounds; but while the hand moves down a distance of six inches, the weight will be raised only one inch. By the use of this machine, then, you would need to apply a force only one-sixth as great as the weight you wish to raise; but you would gain nothing in work,

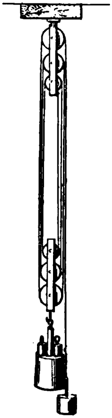

FIG. 74.—A block of pulleys.

because the force must move six times the distance. You would not need to work very hard at any one time, but must continue the work six times as long.

The inclined plane.—The inclined plane is also an important machine and has a very wide use. Any plane surface that slopes is an inclined plane. The roof of a house, the side of a hill, a plank with one end on a wagon and the other end on the ground, are examples of inclined planes.

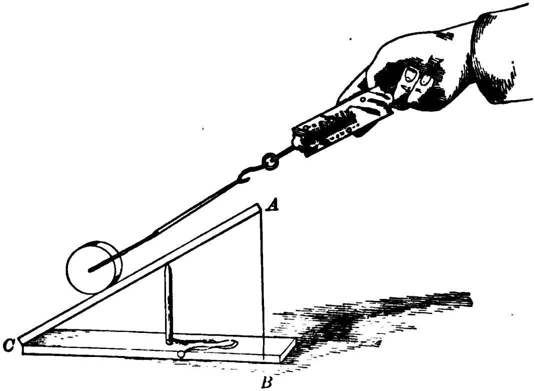

FIG. 75.—The inclined plane.

Experiment 41—Prepare two smooth boards, each six inches wide and a foot long. Fasten one to the other with two hinges in the manner shown in the figure. The upper board can then be raised at one end and propped up at any angle to the other board.

The length of the board, *A C*, Fig. 75, is twelve inches. Raise the end, *A*, until the distance, *A B*, is six inches. The length of the incline is then twice the height of one end of it.

Now prepare some kind of a roller for the incline. One easy way to do this is to get, at a drug-store, a cylindrical wooden box one or two inches long and two inches in diameter. Fill it with bird-shot. Drill a small hole in the centre of each end. Bend a stiff wire in the form shown in Fig. 76, inserting the ends into the holes in the end of the roller. Find the weight of the roller and wire in pounds and ounces. Place the roller on the inclined plane, and roll it up and down to see that it moves with very little friction. Fasten a short string to the handle of the roller and to the hook of the spring-scales.

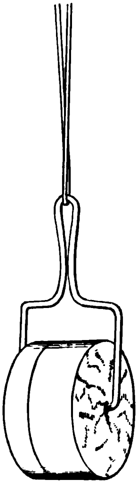
FIG. 76.—Roller for the inclined plane.

Hold the scales so that the string will be parallel to the inclined plane.

If the roller weighs sixteen ounces, then the scales will show that the pull on the string is only eight ounces when the incline is set as shown in Fig. 75.

Set the inclined plane so that *A B* is three inches, and the scales will then show four ounces. Make *A B* two inches, and the scales will show two and two-thirds ounces.

The steeper the inclined plane is made, the greater is the weight thrown onto the scales. When the roller is pulled along the inclined plane, the exact amount of force which must be exerted upon it to keep it from rolling down can be found by measuring the length of the incline and the height of one end of it. Then the pull on the string must always be such a part of the weight as the height of the incline is a part of its length.

Some examples of the use of the inclined plane.—Every day we make some use of the inclined plane as a machine, but often we do not think of the law under which it operates.

Suppose you wish to lift a barrel of salt into a wagon. It weighs nearly 300 pounds, so that it would not be possible for one man to lift it; but by making use of an inclined plane, the man may lift the barrel into the wagon.

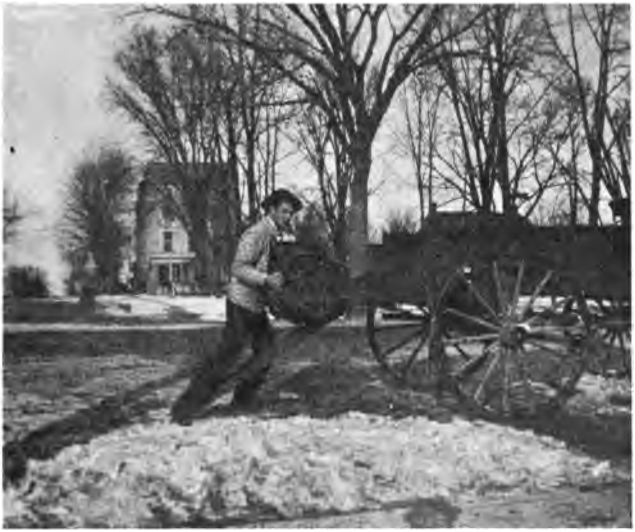

Fig. 77.—Using an inclined plane to raise a barrel of salt into a wagon.

The wagon bed, in Fig. 77, is two and one-half feet from the ground, and the skid laid up at the hind end of the wagon is five feet long. From the experiment you have just performed, it is plain that the man will need to push with only a force of 150 pounds. He must continue to push with this force while the barrel rolls the whole length of the plank, and then he will have raised it only two and one-half feet from the ground.

He has done just as much work as if he had lifted it straight up, but he was able, by use of the machine, to do the work himself.

On account of the friction, he would need to push a little more than 150 pounds to keep the barrel rolling.

The thread on a screw is a narrow inclined plane which passes spirally around a central shaft, as shown in Fig. 78.

A wedge used in splitting wood is also a good example of this kind of a machine.

Think of several uses of this machine.

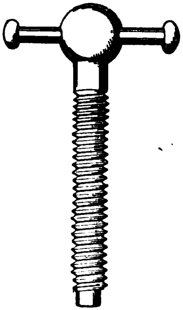

FIG. 78.—The screw as an inclined plane.

Another advantage in the use of machines.—We have learned that a machine must always receive energy before it can do any work. But it is not necessary that the energy should all come from man. The most of it, in fact, comes from other sources.

The steam-engine, the horse, the wind, the water-fall, and so on, are all sources of great energy. The great advantage of machines is that they enable us to use other energy than our own in doing work.

The wind-wheel is made to pump water from a well and do other kinds of work.

The water-wheel makes the great energy of water-falls available for useful work.

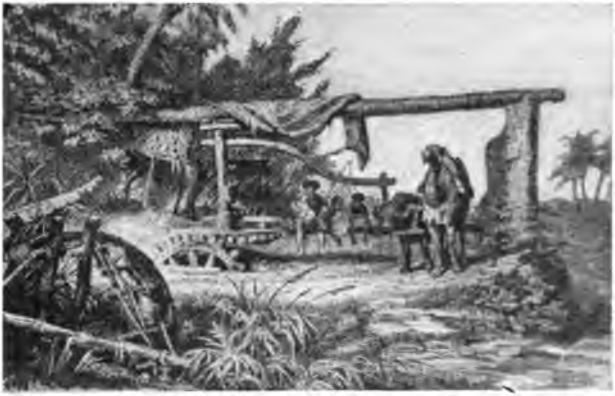

FIG. 79.—An old method of pumping water.

By means of various machines, man can make use of the energy of the horse or other animals.

The steam-engine makes it possible for us to use the wonderful supply of energy which is stored up in coal.

Thus man has been able to relieve himself of a great deal of work, by inventing machines which use energy other than his own. The most advanced people have the best kinds of machines. In Fig. 79 is shown an old way of pumping water. The effort is there being made to use animals in doing the work, but the machine is very crude and ineffective.

Modern ways of living and of doing things are very different from the ways of the ancients, chiefly because of the numerous machines which have been invented for using energy in doing useful work.

QUESTIONS.

1. What is work?

2. What is a machine?

3. Can a machine do work?

4. What are the three classes of levers?

5. What are the three points to be considered in any lever?

6. What is the position of P, W, and F in levers of the first class?

7. State a law of levers.

8. How can a small power be made to balance a large weight?

9. What is the arrangement in levers of the second class?

10. Give some examples of levers of the second class.

11. What is the arrangement in levers of the third class?

12. Give some examples of levers of the third class.

13. Show how a shovel may be used as a lever of the third class or first class.

14. What is a pulley? Show that it is a lever of the first class.

15. What is a fixed pulley? What advantage is there in its use?

16. What is a movable pulley? What advantage is there in its use?

17. Describe an experiment to show the use of an inclined plane.

18. A wagon is three feet high. A plank twelve feet long rests with one end on the wagon and the other end on the ground. How hard must a man push on a barrel that weighs 200 pounds to hold it on the plank? Answer, 50 pounds.

19. How do machines enable us to use other forces than our own?

20. What is one important difference between modern and ancient ways of doing work?

CHAPTER VIII

SOUND

Nature of sound.—We learned in a former chapter that we are constantly surrounded by air which presses upon us on all sides. Any disturbance in the air will start waves which travel out in all directions, much as a pebble dropped into a pool of still water will start ripples out in all directions from that point. But, in case of sound in air, the waves go out in all directions—up, down, and sidewise, while in water we see only the ripples on the surface.

It is plain that it would be a great advantage to us, and to other animals, to have some sense-organ by which we could perceive any disturbance in the ever-present air. The ears are such an organ, and they are delicate enough to perceive very slight disturbances.

Sound-waves will travel in many other substances, such as wood, iron, water, and so on; but nearly all the sounds which we hear come to us through the air. All sounds, whether they be noises, or speech, or music, reach the ear as air-waves.

The nature of a wave.—A wave is a motion which travels on or through a body without moving the body as a whole.

Experiment 42.—Place upon a table a long shallow dish and fill it nearly full of water. Place your eye in such a position that the light from a window or lamp will be reflected to you from the surface of the water. When all is still, touch the surface with the point of a pencil or pin, and fine waves will spread over the water. Float some small particle on the water and try again. It will be noticed that the waves do not carry the particle about, though they may cause it to rise and fall slightly.

It appears, then, that these waves are not water travelling across the dish, but only a motion in the water which moved from one place to the next, and the next, and so on, across the plate.

Experiment 43.—Prepare a grooved board about two feet long and two inches wide.

This may be done by cutting a groove along the middle of the board, or by tacking two strips of moulding onto the board, as in the figure. Place in the groove a number of marbles of the same size, each in contact with the ones next to it. Roll one against the end of the row, and one at the other end will roll away. Each marble was struck by the one behind it, but it quickly passed the motion on to the one ahead. The last one had none ahead of it to strike, and so it kept the motion and rolled away. This illustrates how a wave may travel from particle to particle without scarcely moving the particles themselves.

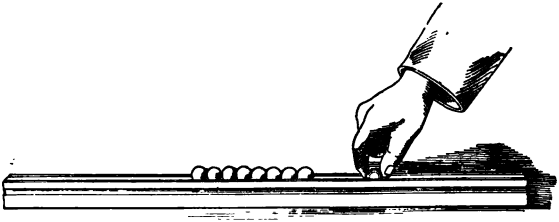

FIG. 80.—Illustration of wave motion.

The cause of sound.—All sound is caused by vibrating bodies. A bell, a tuning-fork, the vocal cords, the wires of a piano, and so on, can all be made to vibrate. While vibrating, they move rapidly back and forth, causing waves in the air. These waves then travel out on the air to our ears and affect the sense of hearing.

That the sound is caused by the vibrating body, may be easily shown by striking a gong or a large church-bell and then touching lightly its rim. The vibrations can be plainly felt. A pencil held lightly against the rim will be made to rebound. Grasp the bell with the hand and the vibrations will be stopped. At the same time all sound ceases. In all cases the sound ceases as soon as the vibrations of a body are stopped.

The nature of sound-waves in air.—Air is closely packed around any sounding body. When the body vibrates, it gives to the air next to it a similar motion. When the side of a bell, for example, moves outward, in vibrating, it pushes the air ahead of it. The air is not thrown away from the bell, but only given a little push. The particles of air next to the bell push in turn upon the particles next to them, and these on the next, and so on, much as each marble, in Experiment 43, received a push from behind, and then pushed the one ahead of it without itself moving very much.

When a vibrating body moves towards the air, the particles of air are crowded closer together, or condensed. When the vibrating body moves back, the particles are given more room, and so the air at that point is more rare. The crowded condition is called a *condensation*, and the rare condition is called a *rarefaction*. The two together form a sound-wave. In Fig. 81 is a representation of sound-waves moving out from a vibrating body at the centre. The dark rings are condensations, and the light ones are rarefactions. From the centre of one condensation to the centre of the next is a wave-length. A wave is sent out each time the vibrating body moves back and forth.

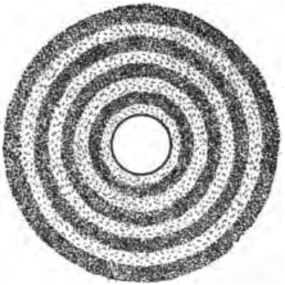

FIG. 81.—Condensations and rarefactions of sound-waves.

Sound-waves in bodies other than air.—A vibrating body may start waves in solids or liquids as well as in gases.

Experiment 44.—Select a light pine board or stick, ten or more feet long. Place on one end of it a watch, and press the other end against the ear. The ticking of the watch may be distinctly heard.

Put a vibrating tuning-fork in place of the watch, and notice that the sound comes from the board, though the fork set the board into vibration.

Experiment 45.—There is a kind of telephone in which electricity is not used; but the vibrations are sent over a string or wire from one station to another. It is easily constructed, and is quite satisfactory for short distances—several hundred feet.

Saw out a square board about 12 x 12 inches, and saw out a circle from the centre of it about seven or eight inches across. Get at the harness shop a piece of good leather cut in form of a circle and about one inch larger in diameter than the hole which was cut in the square board. Tack the leather all around its edge, to the edge of the hole as shown in Fig. 82. Prepare two boards of this kind, one for each station. Fasten them firmly in place, one at each point between which talking is to be done.

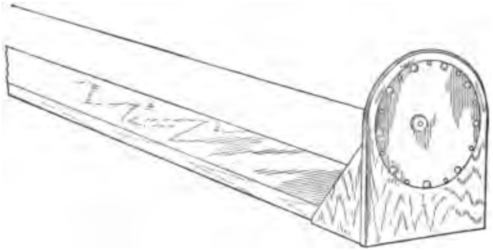

FIG. 82.—One end of a wire telephone.

The distance may be between houses on opposite sides of a street or road, or between houses as much as even a quarter of a mile from each other.

Now stretch a wire, about the size of broom-wire, from one station to the other. Put the end of the wire through the centre of the leather at each end and fasten it to a button. The wire must be whole, that is, there must be no splices in it; it must hang without touching any object along the way, and it must pull hard on the leather at each end. By tapping on the leather with a pencil, one person can call up another at the other end, and a conversation can be carried on in ordinary tones of voice.

In case the distance is very long or a slight turn has to be made, it may be necessary to support the wire. The support should be a soft string only, so as not to stop the vibrations as they pass over the wire.

All kinds of substances will carry vibrations, but some are much better for the purpose than others.

Velocity of sound.—The velocity of sound in the air is about 1125 feet a second. When the air is cold, the sound vibrations move more slowly than when the air is warm. When air is cold enough to freeze water, the sound-waves move through it at the rate of 1090 feet a second; but on a mild summer day, 1125 feet a second.

You can see, almost at once, the smoke from a gun that is fired at some distance from you,—for light travels at very great speed,—but you may not hear the report of the gun for several seconds after.

You may see the steam from the whistle of a locomotive at some distance, but it may be several seconds before the sound reaches you.

You see the flash of lightning at once, but the thunder comes along afterwards. You can tell nearly the distance of a storm-cloud if you will count the number of seconds from the the time you see a flash of lightning and hear the thunder. Suppose the time is six seconds, then $6 \times 1125 = 6750$ feet, the distance of the cloud.

Sound-waves move through water a little more than four times as fast as in air, and through iron nearly sixteen times as fast.

Experiment 46.—Find a long iron tube, such as are often put up in towns for hitching-racks. The tube or iron rod should be fifty or more feet long, and the pieces must be fastened firmly together, end to end. Let one person stand at each end of the rod, one to tap the rod with a stone or hammer, and the other to listen. The listener will hear the tap twice. The first one comes through the iron more rapidly than the second, which comes in the ordinary way, through the air. The railroad track may be used instead of the iron tube in this experiment.

Echo.—When a ball is thrown against a wall, it will rebound. So, also, sound-waves will rebound when they are stopped in their course. The sound which comes back is called an echo.

Experiment 47.—Stand about 200 feet from the long side of a large barn or other building. Face the building, and, when all is quiet, utter a sharp sound, such as *ha* or *ho*. The exact sound you utter will come back, and can be heard a moment after it is uttered.

Move away a distance of five hundred feet, and the echo will not return for nearly one second. Repeat your name or the name of another, and it may all be repeated in the echo.

The sound must travel from you to the building and back again before you hear the echo. When you were 500 feet away, the sound travelled 1000 feet before the echo reached you.

Sound-waves are reflected from any surface which they strike. The sound of music, or of ordinary conversation in a room, is reflected from the walls, but the distance is so small that no echo is heard. The time is so short between the sound that is uttered and its reflection back to the speaker that they are heard together as one sound.

One can make himself heard more easily in a room than out of doors. In a room, the hearers get not only the sound direct from the speaker, but also its reflections from the wall.

The pitch of sound.—Sounds differ greatly in pitch. The upper wires on a piano give a sound of high pitch, and the lower ones low pitch. This difference is caused by the number of sound-waves that reach the ear in a second. When the number of waves per second is great, the sound has a high pitch, and as the number decreases the pitch becomes lower. The number of waves is determined by the sounding body. It sends out a wave every time it vibrates. If it vibrates 200 times a second, then it will send out 200 waves in that time. The pitch of any piano-wire is determined by the number of times it vibrates in a second.

Examine the wires of a piano, and notice how their sounds are made to differ in pitch. The high notes are made by short wires and the low notes by long ones. The shorter a wire is the faster it will vibrate.

You also see that the ends of the wires are fastened to iron pins. By turning these pins the wires may be tightly stretched. The tighter a wire is stretched the faster it will vibrate.

You see, too, that the wires which give the low pitch are made heavy and thick as well as long. The heavier a wire is the slower it will vibrate.

So, piano-wires give notes of different pitch because of their *length*, their *tension*, and their *size*.

This is true of all vibrating wires or cords.

Experiment 48.—Make a wooden box about three feet long and four inches square at the ends. At one end insert two stout screws, and at the other end two small pulleys, as shown in Fig. 83.

Get at the music store some of the smallest piano-wire or strings, such as are used on a guitar. Get two sizes, one being a little heavier than the other. Take a piece, about four feet long, of the fine wire; fasten one end to one of the screws and pass the other end over one of the pulleys and attach it to a light tin bucket or can. Pour into the bucket enough of shot or sand to stretch the wire till it gives a clear musical note when it is plucked with the finger. Now find what note this is by use of a tuning-fork or a piano. If neither of these is present, sing the note, and remember the pitch until you place the triangular bridge under the middle of the wire. The middle is half-way between the top of the pulley and the other end of the box.

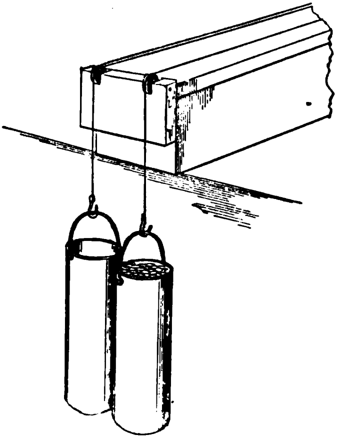

FIG. 83.—One end of the sonometer. The wires at the other end pass over a bridge and are fastened to screws at the end of the box.

Now pluck the wire on one side of the bridge, and it will give a note one octave higher than the whole string gave. The pitch of a note is one octave higher whenever the number of vibrations are twice as many in a second. So a string which is half as long will vibrate twice as fast. If it is made one-fourth as long, it will vibrate four times as fast, and give out a note two octaves higher than the whole wire.

Next, take out the bridge and mount another wire of the same size and kind. Pour shot or sand into the second bucket until both wires have the same pitch. Weigh one of the buckets with the shot which it contains. Then pour more shot or sand into one of the buckets until its string gives a note one octave higher than the other. Then weigh this bucket, and it will be found to be four times as heavy as the other—that is, there will be twice as many vibrations where the tension is four times as great. There would be three times as many when the tension is nine times as great, and four times as many when the tension is sixteen times as great.

Next, replace one of the wires or cords with a heavier one. Make both the same length, and hang equal weights on their ends. It will be found that the heavy string will give a note of lower pitch—that is, it will vibrate more slowly. If one wire is four times as heavy as another, it will vibrate one-half as fast; if it is nine times as heavy, it will vibrate one-third as fast; sixteen times as heavy, one-fourth as fast, and so on.

By this simple piece of apparatus these three important laws of vibrating strings may be proven.

Loudness of sound.—The loudness of sound is determined by the distance through which a vibrating body moves when it produces the sound. When a bell is struck a hard blow its vibrating parts will move back and forth through a considerable distance.

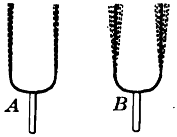

FIG. 84.—Vibrating prongs of tuning forks.

If a tuning-fork be lightly tapped, its prongs will move back and forth through only a small distance, as represented by *A* in Fig. 84. If the fork be forcibly struck, its prongs will move through a greater distance, as shown in *B*, and the sound will be much louder. The fork makes the same number of vibrations, whether the sound is weak or strong; and so the pitch will not be changed when the sound is made louder.

The prongs of the fork, *B*, move farther in the same time, and so must move faster. On this account they will crowd the air-particles more closely together in the condensations, and draw them farther apart in the rarefactions. A wave of this kind will beat harder upon the drum-head of the ear, and in that way we can tell a loud from a soft sound. This is true of all sounding bodies.

The loudness will diminish rapidly as one moves away from a sounding body. You may hear a sound distinctly at a distance of 100 feet; but if you move away 200 feet the loudness will be only one-fourth as great; at 300 feet, one-ninth as great; at 400 feet, one-sixteenth as great, and so on. This is because the sound is allowed to go out in all directions.

If the sound is made to go through a tube, as in speaking-tubes, then it is nearly all forced to go in one direction, and even a weak sound may be heard at the other end of a very long tube.

Experiment 49.—Secure a tube ten or fifteen feet long. Suspend a watch at one end of it, as close as possible, but without touching the tube. The ticking of the watch can be heard at the other end. Tin tubes, such as are used in spouting, are very good for this purpose.

Music.—Every one is pleased by good music. Even the lower animals are often much affected by music.

All music is caused by the regular vibrations of some kind of a vibrating body, and is carried by waves of air to our ears.

The piano, the organ, the violin, the horn, and all other kind of musical instruments, are made to start air-waves. When these waves are of the right kind and the right combination, good music will be the result.

Experiment 50.—The Æolian harp.—Select a piece of board about two inches wide, and long enough to fit into a window beneath the lower sash. The board should be some hard wood. Fasten near each end of the board a bridge with five or six short steps, as shown in Fig. 85. Stretch fine steel wires or catgut strings along the board, one on each step, and fasten their ends to stout screws. Turn the screws until each wire gives a clear note when plucked, and all have the same pitch. Then place it in the window, raising the sash just enough to make room for the instrument. The draft of air through this crevice will cause the strings to vibrate and give out many beautiful harmonies,—sometimes loud and then low and sweet, depending on the strength of the draft of air. The strings will also often break up in different lengths, causing a difference in pitch and producing beautiful harmony. The harp may sit on the sill just in front of the sash. A gentle draft of air is best and the height of the sash should be varied till the best results are obtained.

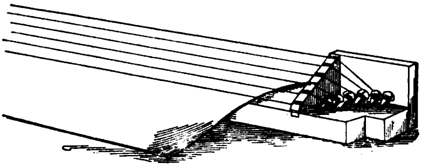

FIG. 85.—One end of the Æolian harp.

QUESTIONS.

1. How do sound-waves travel?
2. What is a wave?
3. How may water-waves be examined?
4. What is the cause of sound? How can you prove it?

5. What is a condensation?

6. What is a rarefaction?

7. Explain how you can telephone without using electricity.

8. How fast does sound travel?

9. If you see the flash from a gun and hear the report two seconds later, how far distant was the gun?

10. How could you show that sound travels faster through iron than through air?

11. In what three ways are piano wires made to give notes of different pitch?

12. When a vibrating string is made half as long, how much is the pitch changed?

13. When the tension of a string is made four times as great, how much is the pitch changed?

14. What effect do heavy wires have on pitch?

15. How is a body made to give a loud sound?

16. Explain how one can hear distinctly through a tube.

17. How is an Æolian harp made?

CHAPTER IX

LIGHT

Use of light.—Light is the best means we have of gaining knowledge of things that are far from us as well as the things that are near by. We cannot feel objects unless we come in contact with them; we can hear the sounds which come from objects only a short distance away; but we can see objects which are thousands and even millions of miles away. One great use of light, as far as man and other animals are concerned, is to affect the eye and give knowledge of the objects from which light comes.

How light travels.—All space is filled with *ether*. We do not know just what ether is; but we know it is everywhere, in wood, in iron, in glass, in air, and in all the space beyond the air. All matter is only embedded in the ether.

Light travels on the ether in the form of waves. There is ether in all the space between the earth and the sun, and so the light-waves from the sun can travel to the earth. The light from the far-away fixed stars comes all the way on the ether. Light-waves travel only on ether. They may pass through air, glass, water, and other substances, but these are, to some extent, in the way of the waves.

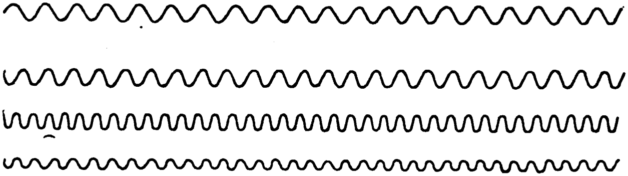

FIG. 86.—Undulating waves.

Sound-waves cannot travel on ether. Light-waves are in the form of a wavy line and are called undulations. Several waves may be represented by the lines in Fig. 86.

A candle, a lamp, an electric light, or any source of light, can cause disturbances in the ether. This disturbance travels out in all directions in the form of undulating waves of ether. When these waves enter the eye and fall upon the retina, they produce the sensation called vision. The speed of light-waves is about 185,000 miles a second.

What objects can be seen?—*We see an object only by the light which comes from it to* *the eye.* Nothing goes out from the eye *to* the object at which we look.

We can see only those objects, then, from which light *comes* to us.

Some bodies give out light of themselves. They are called *luminous* bodies. The sun, a lamp, a fire, and a red-hot ball of iron are examples of luminous bodies. They send out waves of light, and we see them whenever the waves enter the eye.

Most objects are not seen by the light which they themselves send out, but light from a luminous body falls upon them and is reflected, as a ball is reflected when thrown against a wall. Such objects are seen by the reflected light which comes *from* them *to* the eye. Such objects are said to be *illuminated.* A house, a picture, a tree, the face of a friend, and this page are examples of objects that are seen by reflected light.

The sun is our greatest luminous object, and it gives forth nearly all the light we have on earth.

The moon is seen only by the light which it receives from the sun and then reflects to the earth. One whole side of the moon is at all times illuminated, while the other side is dark.

When we see half the bright side, we say the moon is half full. The moon is full all the time, but we cannot always see it. Sometimes the whole bright side is towards us, and at other times only the dark side.

Light travels in straight lines.—The directions in which waves of light travel are called *rays*. A luminous body at the centre, Fig. 87, will send out rays in all directions.

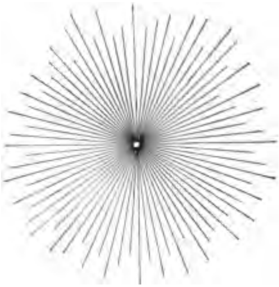

FIG. 87.—Rays of light.

Each ray is a straight line. If you hold a book between your eyes and a lamp, the rays do not bend around the book to the eye, and so the lamp cannot be seen.

Experiment 51.—Secure a piece of heavy, dark paper about one foot square or larger.

Through its centre make a small pinhole. Hold this paper about one foot or more from a candle or lamp of any kind, so that a few rays of light may come through the pinhole and fall upon a sheet of white paper which is held a little way back of the hole. Since the rays travel in straight lines, all the rays that get through the hole will cross at that point and pass straight on to the sheet of paper back of it. So a ray or more from each point of the candle will fall upon a corresponding point of the white paper and form an image of the candle there. Since the rays cross at the pinhole, the image, of course, will be upsidedown and reversed from side to side. Try various distances from the candle and between the papers.

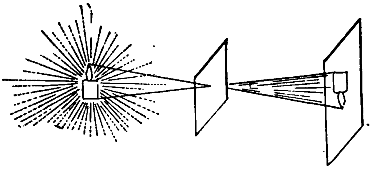

FIG. 88.—Image through small aperture.

Intensity of light.—It is well known that light becomes dimmer and dimmer as one moves farther away from its source. The cause of this may be plainly seen by a study of Fig. 89. The point *O* is a source of light. It will send out rays in all directions, and a number of them will fall upon the square *A* and illuminate it. The rays move in straight lines, so that if the ones which just graze the corners of *A* be extended out to twice the distance from *O*, they will come to the corners of a square which is just four times as large as *A*. The same number of waves which fall upon *A* will fall upon *B* when *A* is removed. So, then, the same amount of light must spread over four times the space, and the intensity can be only one-fourth as great. At three times the distance the area of the square would be nine times *A*, and the intensity of the light only one-ninth as great. At four times the distance, one-sixteenth as great, and so on.

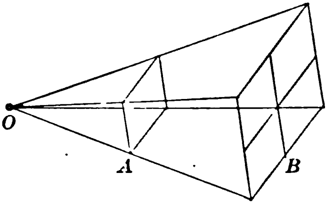

FIG. 89.—**The same amount of light must cover four times the space at twice the distance, and so is one-fourth as bright.**

Shadows.—Objects through which waves of light cannot pass are called *opaque*. Iron and wood are examples of opaque substances.

Objects through which waves of light readily pass are called *transparent*. Glass, mica, and water are examples of transparent substances.

When waves of light strike an opaque body, they are stopped in their course, and a shadow is formed. The opaque sphere between the candle and the screen in Fig. 90 shuts off all the light of the candle from the small circle in the centre of the screen. This shadow is called the *umbra*. It receives no light from the candle. Around the umbra is a shadow which received some, but not all, the light that would come to it. It is called the *penumbra*.

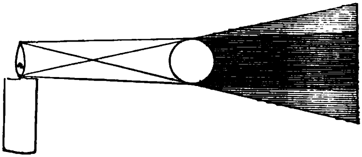

FIG. 90.—The umbra and penumbra.

When the source of light is a point, there is no penumbra. In this case the shadows are very sharp. That is why the shadows from an electric lamp are so sharp, all the light coming from a small spot on the end of the upper carbon. When light comes from the broad side of an oil lamp, there is always a penumbra, in which the shadow shades off into the light.

Night.—The earth is an opaque body, and its shadow is night. The sun is much larger than the earth, and so the shadow of the earth would be like that shown in Fig. 91. When any one is on the side of the earth opposite the sun, he is in this shadow, which is the umbra. Night, then, has the form of a cone with its base on the earth and its point extending out a distance of about 850,000 miles from the earth.

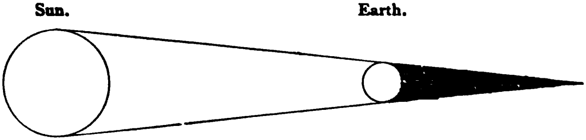

FIG. 91.—The shadow of the earth. Night.

Eclipses.—Several eclipses of the sun and of the moon occur every year. Any heavenly body is said to be eclipsed when it moves into the shadow of another body or when a third body comes between it and us. The moon is only about 240,000 miles away from the earth and the earth's shadow is about 850,000 miles long. As the moon revolves about the earth, it often moves into this shadow. We can see in Fig. 92 that the moon must always be on the opposite side of the earth from the sun when it is eclipsed, and so it will always be full at that time.

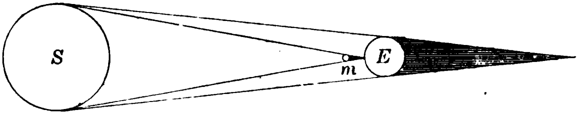

FIG. 92.—Shadow of the moon and eclipse of the sun.

An eclipse of the sun is caused by the moon coming between us and the sun. This position is shown in Fig. 92. The shadow of the moon is just about as long as from the moon to the earth. For this reason we never see a total eclipse of the sun unless we are in the point of the moon's shadow. Astronomers can calculate in advance just where the shadow will fall upon the earth, and they often travel a long distance to get a position in the shadow that they may observe a total eclipse of the sun.

Reflection of light.—Whenever waves of light strike a smooth surface, a part or all of them rebound from the surface and continue on their way, but in a different direction. This is called *reflection* of light.

Some surfaces reflect light much better than others. A mirror is a good reflector. A smooth board when varnished will reflect light fairly well. Black cloth is a poor reflector. All surfaces reflect light to some extent.

The law of reflection.—Let the horizontal line, Fig. 93, represent a mirror. Let a perpendicular be drawn from *D* to the mirror. A ray of light, as shown by the arrow-head, makes, on approaching the mirror, a certain angle with the perpendicular. This angle is called the *angle of incidence*. The ray is then reflected from the mirror, making another angle on the other side of the perpendicular, called the *angle of reflection.*

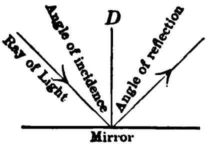

FIG. 93.—Angles of incidence and reflection.

The law of reflection is: *The angle of reflection is always equal to the angle of incidence.*

Experiment 52.—Get a smooth board of light colored wood, about one foot square.

Draw a straight line from the middle of one edge to the middle of the opposite edge. This line should, then, be perpendicular to the edge of the board. Describe a semicircle on the board as shown in Fig. 94. This may be done with a string and pencil. Then lay off equal spaces on the semicircle on each side of the perpendicular line. Draw lines from these points to the centre of the circle. This will give equal angles on each side of the perpendicular.

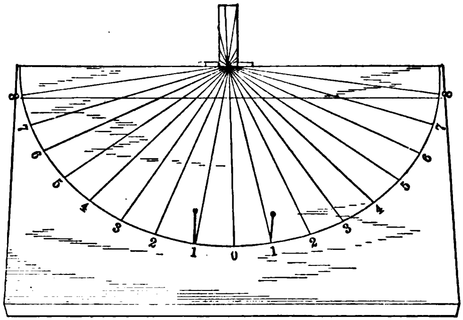

FIG. 94.—Apparatus for showing the law of reflection.

Now fasten a small mirror to the edge of the board. It may be an inch or less wide and three inches or more long. Place it in an upright position at the centre of the circle. It can be held in place by a little glue or a wooden cleat. The apparatus is now complete.

Stick a pin into the board at the opposite end of the perpendicular from the mirror. Then look along the head of the pin to the image of the pin in the mirror. If the pin and its image appear in the same straight line, then the light is being reflected straight back to the pin, and this shows that the mirror is properly set. If this is not found to be the case, then change the mirror slightly until this condition is obtained.

Then place the pin at various points along the semicircle, and it will be found that the eye will have to be placed at a corresponding point on the other side of the perpendicular before the pin can be seen in the mirror. Try many different positions of the pin, and show that in all cases the law of reflection is true.

Where we see the image.—We always see an object in the direction of a light-wave when it *enters* the eye. No matter what course a wave may have travelled or how often it may have been reflected, its course at the time it enters the eye will determine the direction in which we will see the object. If the rays come straight from the object to the eye, then we see the object where it actually is. But when the rays are bent out of a straight line, we can still see the object, but not where it actually is. A ray may start from *A*, Fig. 95, and be reflected from the mirror, *M*, to the eye. The eye will then appear to see the object along the line of the reflected ray, at *B*, a point just as far back of the mirror as *A* is in front of it. When you stand a little to one side of a large mirror, you cannot see yourself, but you may see other persons in the room. They appear to be back of the mirror. If they look into the mirror, they cannot see themselves, but they can see you. Whenever you can see any one in a mirror, that person can also see you.

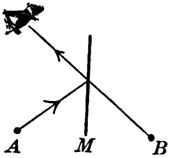

FIG. 95.—Image in a mirror.

In Fig. 96 is shown an arrangement of four mirrors, so placed that the first one throws the light straight down, the second one throws it across, the third one throws it up, and the fourth one reflects it out to the eye in the same direction it had before it came to the first mirror. The eye will then see an object just as though the rays had come straight to it. The brick which is held between does not interfere with the rays, for they are bent around it. Mirrors are sometimes arranged in this way and concealed in a neat box. Some people pay to look through such a box, and are made to believe that they can see through their hands or heads when they are placed in the position of the brick in the figure.

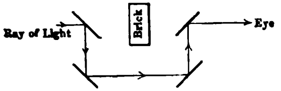

FIG. 96.—A bent ray of light.

Refraction.—Whenever a ray of light passes obliquely from one transparent substance into another one, it is bent out of its course. This bending is called *refraction*. Refraction occurs only when a ray enters a substance obliquely. In Fig. 97 may be seen the path of two rays. The one which is perpendicular to the water passes straight on, but the one which strikes the surface obliquely is bent on entering the water.

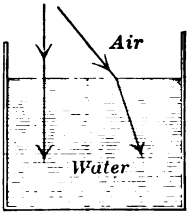

FIG. 97.—Refraction of rays of light.

Experiment 53.—Hold a pencil back of a piece of plate-glass so that part of the pencil may be seen above the glass and a part behind it. Look obliquely through the glass at the pencil. The part of the pencil behind the glass will appear to be moved to one side. This is caused by refraction. The rays of light from the pencil were refracted on entering and leaving the glass. Since we always see an object in the direction the light enters the eye, the part of the pencil behind the glass will appear to be in the direction the light comes to the eye after passing through the glass.

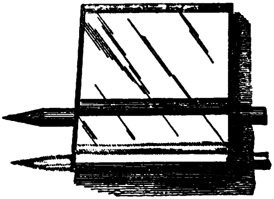

FIG. 98.—A pencil viewed obliquely through a piece of plate-glass.

Some instances of refraction.—One method of fishing is to thrust a spear into a fish seen at the bottom of clear water five or six feet deep. If the fisherman is directly above the fish, he will see it in its correct position; but if he looks into the water obliquely, he will always thrust the spear beyond the fish. The ray of light from the fish is bent, as shown in Fig. 99, when it passes from water to air, and the fish appears to him to be along this line.

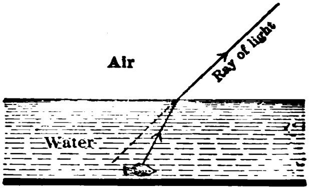

FIG. 99.—Refraction from water to air.

Experiment 54.—Place a pencil or stick into a vessel of water. It appears to be abruptly bent at the surface of the water. This also is caused by refraction. Rays of light from the part of the stick beneath the

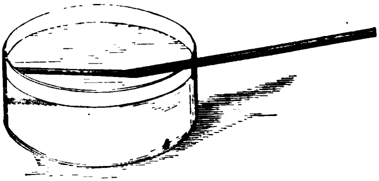

FIG. 100.—A stick appearing bent when under water.

water are bent on coming out into the air, and so that part of it is not seen in its true place.

The light from the sun and stars must come through the air before it reaches us. The light from a star near the horizon must pass obliquely through the air, and so is bent down as shown in Fig. 101. The eye then looks along the rays after they have been bent, and sees the star higher than it is in fact. All heavenly bodies except those directly overhead are raised in this way. A star directly overhead, that is, in the zenith, sends its rays straight down through the air, and in this case, as we have learned, there would be no refraction.

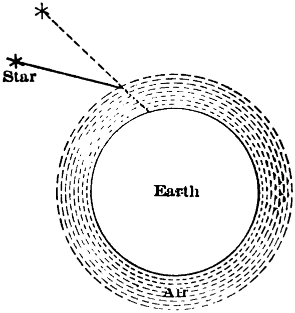

FIG. 101.—Refraction of light.

On account of the refraction of light by the air, we can see the sun before it has actually risen above the horizon, and also after it has set on the other side. At the equator this makes the day nearly five minutes longer than it would be if there were no refraction. At places north and south of the equator the increase in the length of the day is still more.

Refraction in a prism.—A prism is a transparent body with two of its sides plane and meeting at an angle. They are ordinarily made of glass. The end of a triangular prism is shown in Fig. 102. When a ray of light from *o* strikes one side of the prism obliquely, it will be refracted by the glass. Then it passes straight through the glass, and on coming out into the air it is bent again in the same direction.

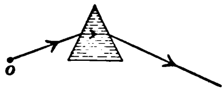

FIG. 102.—Refraction in a triangular prism of glass.

Experiment 55.—Secure a square bottle of clear glass and fill it with water. Hold the bottle horizontally, with one edge up. Look through the two upper adjacent sides. The light from objects beyond does not come straight through. The upper part of the bottle is thus being used as a prism. Look towards a lighted candle. The candle will appear to be much

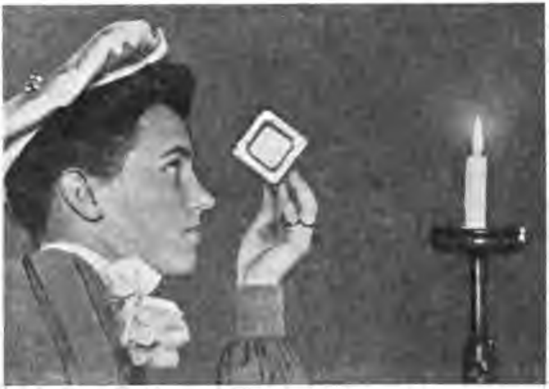

FIG. 103.—Refraction of rays of light while passing through a prism.

higher than it is. Draw lines to represent the rays of light and show the cause of this appearance.

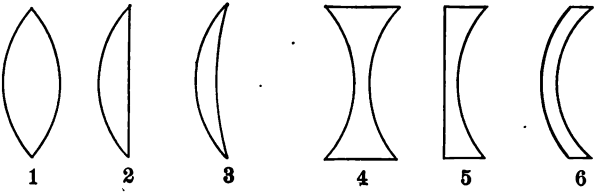

FIG. 104.—Sections of convex and concave lenses.

Lenses.—A lens is similar to a prism, only the sides are curved instead of plane. There are two classes of lenses, the *convex* and the *concave*. In Fig. 104, 1, 2, and 3 show sections cut through the centre of convex lenses. The other three are sections of concave lenses.

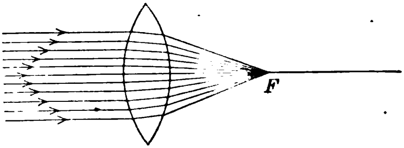

FIG. 105.—Rays of light refracted by a convex lens and brought to a focus at F.

Convex lenses always refract rays of light so as to cause them to meet, or at least come closer together. Fig. 105 shows how a convex lens will refract parallel rays of light and bring them all together at a point. This point is called the *focus* of the lens.

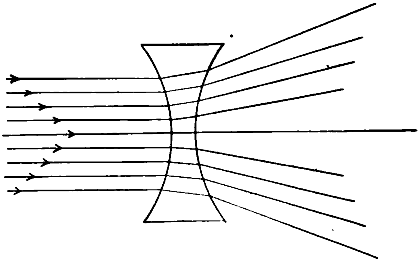

FIG. 106.—Rays of light refracted and scattered by a concave glass.

A concave lens always refracts the rays so that they will be spread farther apart. Fig. 106 shows the effect of a concave lens.

Experiment 56.—When the sun is shining brightly, hold a reading-glass in such a position as to catch as many of its rays as possible. Hold a piece of black cloth or board on the side of the lens opposite the sun. Vary the distance until the spot of bright light is as small as possible. Smoke will arise from the cloth because so much light has been bent to that point,—the focus. A reading-glass is a double-convex lens, that is, it is convex on both sides. This experiment may also be made with a small magnifying-glass, but it will not start a fire so readily.

The transparent part of the front of the eye is the *cornea*. The cornea is a convex lens. Just back of the iris of the eye is another lens, which is double-convex. The purpose of both these lenses is to bend the rays of light so that a distinct image of an object will be formed on the retina in the back part of the eye. Often the lenses of the eyes are deficient. Some people are near-sighted, some are far-sighted, and others have various other defects. Glass lenses can be made just the right shape to correct the defects in the lenses of the eye. Some eyes require convex glasses and others concave ones.

Colors in white light.—The light which we receive from the sun is called *white light.* It is composed of a number of different colors which may be separated from each other.

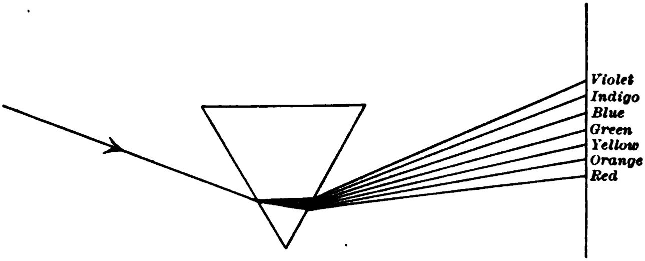

FIG. 107.—Refraction and dispersion of sunlight, giving the solar spectrum.

A glass prism not only refracts light, but also separates it into its various colors. Admit sunlight into a room and hold in it a glass prism. Turn the prism about until you find a beautiful band of colors on the wall or ceiling of the room. This is called the *solar spectrum.* You can readily see three distinct colors, but try to make out the seven prismatic colors—

red, *orange*, *yellow*, *green*, *blue*, *indigo*, and *violet*. As can be seen in Fig. 107, the red is refracted the least and the violet the most.

Rain-drops will refract light and separate it into these colors. When we are between the sun and a rain-cloud, the beautiful rainbow can be seen.

QUESTIONS.

1. In what way is light more useful to us than sound?

2. How does light travel?

3. How fast do light-waves travel?

4. When can we see an object?

5. What are luminous bodies? Name several.

6. What is an illuminated object? Is the moon a luminous or an illuminated object?

7. What are rays of light? In what direction do they travel?

8. Describe how an image can be formed by use of a pinhole in a card-board.

9. How does the intensity of light decrease as you go farther and farther from its source?

10. Distinguish between opaque and transparent bodies.

11. What are the two kinds of shadows?

12. What is night?

13. What is the cause of eclipses?

14. Why is the moon always full when it is eclipsed?

15. What causes an eclipse of the moon?

16. Why do we so seldom see an eclipse of the sun?

17. What is reflection of light?

18. Make a diagram, and point out the angle of incidence and the angle of reflection.

19. State the law of reflection.

20. How can you prove the law of reflection?

21. Where is the image in a mirror located?

22. In what direction do we always see an object?

23. What is meant by the refraction of light?

24. Explain some instances of refraction.

25. What is a prism?

26. What are the two kinds of lenses?

27. What effect do convex lenses have on light?

28. What effect do concave lenses have on light?

29. What is the cornea?

30. Of what use are spectacles?

31. What is white light?

32. Name the colors of the solar spectrum.

CHAPTER X

HEAT

What heat is.—Heat is not a substance like water, iron, or air. It is a condition of a substance. When water is heated, no material substance goes into it. It is just the same water it was before, but its condition is changed. What is this change of condition? When a substance is heated, the molecules of which it is composed are made to move more rapidly. When it is cooled, they are made to move more slowly. The change of condition which we call heat is, then, simply a change in the rapidity of motion of the molecules.

The molecules of a substance are always in motion, even when very cold, though the motion may be very slow. Heating a body is simply making its molecules move faster.

Heat is molecular motion.

Sources of heat.—The *sun* sends a great deal of heat to the earth. The air, water, and ground are warmed by the sun. If the sun should suddenly become a cold body, our earth would also soon become so cold that it would not be possible for animals or plants to live.

We have various ways of producing heat. One way is by *friction*. When two bodies are vigorously rubbed together they become warm and often very hot.

Experiment 56.—Rub a smooth metal button rapidly back and forth on a pine board or on the coat-sleeve. It will soon become so warm that it cannot be held in the hand. The friction between the surfaces caused the molecules of the button to move more rapidly.

The old way of starting a fire was by the friction of one piece of wood on another. This was often done by rotating an upright piece of wood which was sharpened at the lower end and rested on a soft board. The rotation was done by wrapping the bowstring once around the stick and then pushing the bow rapidly back and forth, after the manner shown in Fig. 108.

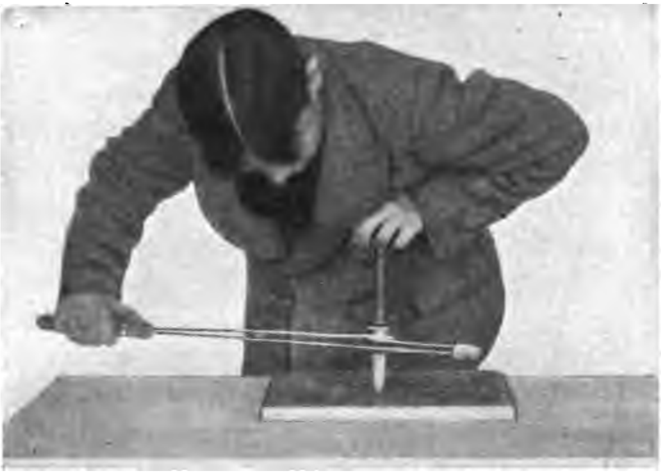

FIG. 108.—Starting a fire by friction.

FIG. 109.—Starting a fire by friction.

Experiment 57.—On a clear day, when everything is very dry, you may succeed in starting a fire by rubbing a piece of an old dry rail upon another rail of the same kind. The boy in Fig. 109 is trying this. The rail must be old and very dry. You will need to work hard and rapidly and confine the friction to one spot.

The old way of setting fire to the powder in guns and pistols was by causing a piece of flint to scrape against iron. The friction would cause a spark and the spark would ignite the powder. In Fig. 110 is shown an old horse-pistol of this kind. The flint is fastened in the hammer. When the trigger is pulled, the flint strikes against the iron in front of it, and the sparks fall onto the powder in the flash-pan

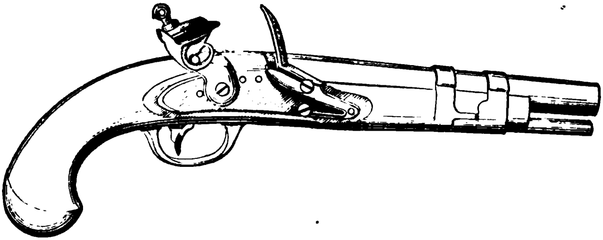

FIG. 110.—A flint-lock horse-pistol.

below. A small hole leads from the flash-pan to the powder in the pistol.

There are numerous instances of heat developed by friction. You have all seen the swarm of sparks that fly from an emery wheel when used in grinding iron. Similar sparks may be seen at night from between the brakes and the car-wheels when a train is coming into a station.

Heat is developed wherever there is friction. It is often difficult to avoid great heat in the running of machinery. Water is poured onto a grindstone so that the tool which is being ground will not be overheated. Oil is poured onto the bearings of machines to prevent friction and heating. In turning and planing iron, the motion must be slow, or the tool will be overheated and will lose its temper.

A second way of producing heat is by *percussion*, that is, the striking of one body against another.

Experiment 58.—Place any small piece of metal, as a penny, a bullet, or piece of copper or iron, on an anvil or stone, and strike it hard several times with a hammer. It may become so hot that it cannot be held in the hand. The motion of the hammer was stopped when it struck, but the molecules of the penny took up the motion, and it is their rapid motion which we call the heat.

When a swiftly moving lead bullet strikes against a steel plate, the heat is often great enough to melt the bullet. In all cases where a moving body is stopped, heat will be developed.

A third way of producing heat is by *chemical action*. This is our commonest source of heat, for the burning of wood, coal, and gas are chemical actions.

We have already explained that the oxygen, which constitutes about one-fifth of the air, is a very active gas, and will combine chemically with many other substances. If there were no oxygen, the wood, coal, and gas would be of no use as a fuel, for they would not burn. Burning is a chemical action between oxygen and some other substance. That is the reason we use dampers to regulate the fire in a stove. If we would shut out all the oxygen, the fire would at once "go out."

It is fortunate for us that the oxygen of the air is mixed with a large amount of the inactive nitrogen. Otherwise it would not be possible for us to control a fire after it is once started. Even our iron stoves would burn.

The action of pure oxygen may be shown by the following experiment:

Experiment 59.—Buy at a drug store four or five ounces of pulverized potassium chlorate. This chemical is rich in oxygen, and when it is heated the oxygen will be given off.

Get also a large, long-handled spoon of the kind called granite-ware. The tin spoon will do, but a hole will be burned through the bottom of it the first time it is used, and there is danger of accident.

Also, prepare four or five pieces of wire picture-cord, each about eight inches long, and spread the wires apart slightly at the end of each piece.

Have a pinch of flour of sulphur at hand, and an alcohol lamp or Bunsen burner for heat. We are now ready to make the experiment. Fill the spoon with potassium chlorate, even full or slightly heaping. Hold it over the flame of the alcohol lamp or Bunsen burner. Soon the chlorate of potash will begin to melt. When it is all melted, it will be a thin, clear liquid and very hot. It is now giving off oxygen. Throw a match into the spoon. It will at once take fire whether it has any head on it or not, and will burn brilliantly till every particle of it is consumed.

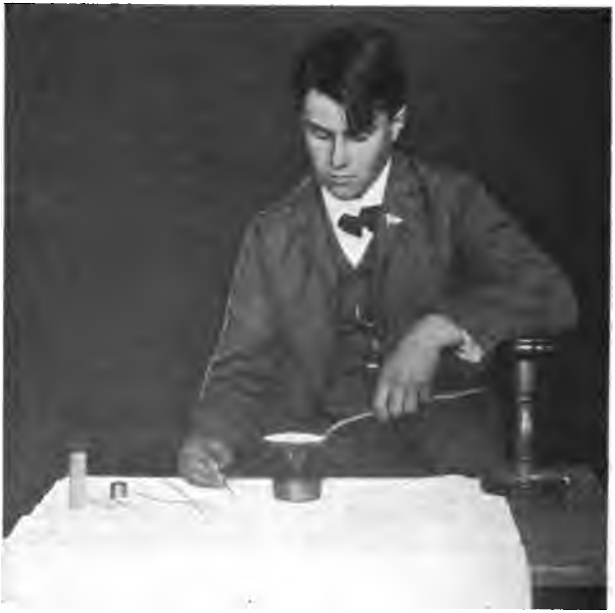

FIG. 111.—Preparing to burn a wire picture-cord.

Now take one of the pieces of wire picture-cord, hold one end of it for a short time in a flame, and at once dip it into the sulphur. Some sulphur will stick to it and will burn with a blue flame. Hold this at once just at the surface of the liquid in the spoon, the spoon being held over the hot flame all the time. The sulphur will quickly burn away and will ignite the iron in the wire. As the wire burns, keep pushing it down so that the burning end is just touching the surface of the liquid in the spoon. Fig. 112 is a photograph of a wire burning in this way.

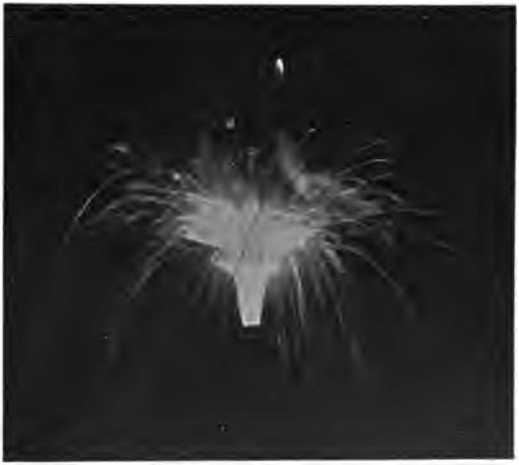

FIG. 112.—Burning a wire picture-cord.

You need have no fear of the sparks, as they will not burn you. The only danger will be that you may spill some of the hot potassium chlorate. It is best to perform the experiment on an old table or board, and a bucket of water should be at hand, that the spoon may be thrown into it in case it is necessary.

The experiment may be made over the flame of a gasoline stove very successfully, or even upon a hot stove of any kind.

In case the sulphur burns away without igniting the wire, turn the other end or take another wire, light it with sulphur and try again.

The oxygen will continue to come for some time if the spoon is kept hot.

This is a valuable experiment, and a little experience will enable one to perform it with ease.

The inactivity of the other gases of the air may be shown by the following simple experiment:

Experiment 60.—Phosphorus is a substance that burns very readily, and will continue to burn as long as any oxygen can get to it, until it is all consumed.

Get a piece of round electric-light carbon about one-half inch long, and dish out one end of it with a penknife or other convenient tool.

Cut a groove around the middle of it. Fasten one end of a wire around the groove and have the wire about a foot in length. Bend the wire as shown in the figure. Place a piece of phosphorus as large as a grain of corn into the hollow which you made in the carbon. Light the phosphorus with a match and at once invert over it a quart bottle or fruit jar. Lower all into a bucket, or other vessel full of water, until the mouth of the bottle extends a little way into the water and the burning phosphorus is about half-way up in the jar.

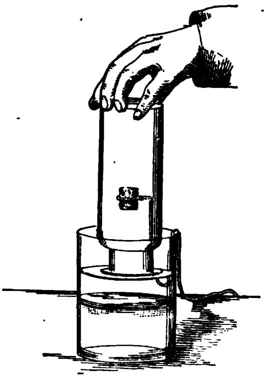
FIG. 113.—Burning phosphorus to remove the oxygen.

Some bubbles may at first escape from the bottle on account of the heating of the air, but soon the water will begin to rise in the bottle, showing that the phosphorus is burning the oxygen out. Wait for several minutes until all burning appears to have ceased, then push down on the wire and remove the carbon from the bottle, being careful to keep the mouth of the bottle under the water while doing so. Now slip a card over the mouth of the bottle, enclosing all the water which has risen into it. Set the bottle right side up on the table. Estimate from the amount of water in the bottle what part of the bottleful of air must have been oxygen.

The gases left in the bottle are nitrogen, argon, and a little carbon dioxide.

Plunge a lighted match into the bottle, and the fire will be quenched as though it had been plunged into water. Try with burning splinters of pine and note a similar effect.

We see from the last two experiments that oxygen is the gas that causes things to burn, and all the other gases tend to check the activity of the oxygen. These gases are mixed together in the proper proportion, so that we may have a fire when we want it and can in most cases keep it under control.

Temperature.—Temperature is the *degree* of heat in a body. It is very different from the *amount* of heat. A bucketful of rain-water will contain more heat than a teacupful of boiling water, but the temperature of the boiling water is much greater. When a large kettleful of water is placed on a hot stove, it is some time before it is even warmed, while a little water in a pan will boil in a minute, but the amount of heat in the kettle is greater. When we find a body is very hot, we would be wrong in concluding that it contains a great deal of heat, unless we know that the body is large.

Hot and cold.—The terms *hot* and *cold* are often used by us when we judge the temperature of any body by our sense of feeling. The temperature of our blood is at all times about 98° Fahrenheit. When the temperature of any body is a little greater than 98° we call it warm, and when it is much greater we call it hot. When the temperature is a

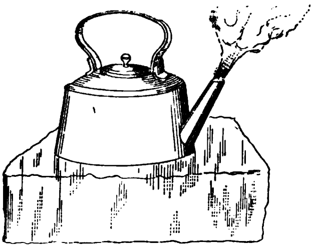

FIG. 114.—Liquid air boiling on a block of ice.

little less than 98° we say it is cool, and when it is much less we say it is cold.

All substances that we know contain some heat, no matter how cold they may seem to us. Even ice may be said to be hot when we compare it with some other substance that is much colder than ice. In Fig. 114 is shown a kettle on a block of ice. The kettle contains liquid air which is exceedingly cold. It is made to boil rapidly by the heat which it receives from the ice.

Our sense of feeling is not very reliable in judging the temperature of bodies, as is shown by the following experiment:

Experiment 61.—Prepare three vessels of water. Have the water in one hot, in another warm, and in the third cold. Place the fingers of one hand into the hot water, and of the other into the cold water. Hold them there for about one-half minute, then put both into the warm water. The warm water will feel cool to the hand from the hot water, and warm to the hand from the cold water.

It is plain that we need some way which is more reliable than our sense of feeling in finding the temperature of bodies. There is an instrument called a thermometer which will always give the correct temperature.

The thermometer.—A thermometer is a glass tube with a very fine hole running lengthwise through the centre, and a bulb on one end of it. The bulb is in most cases filled with mercury and the top of the tube is sealed. When mercury is warmed, it will expand and push some of itself up the tube. The hotter it becomes, the higher the mercury must rise to get room for its increased volume. When it is cooled, the mercury does not need so much room, and so it falls back towards the bulb.

Two kinds of thermometers are in common use. One is named *Fahrenheit* and the other *centigrade*. They are just alike except in the marks which are made upon them. In the one shown in Fig. 115 the space between the freezing and the boiling of water is divided into 100 equal parts. That is the reason it is called centigrade, the word meaning 100 steps.

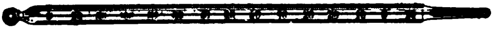

FIG. 115.—Centigrade thermometer.

In the one shown in Fig. 116, the space between the freezing and boiling of water is divided into 180 equal parts. But the freezing temperature of water is marked 32° above zero, and so the boiling point is 212°. This thermometer was devised in the early part of the eighteenth century by a man named Fahrenheit, and hence its name.

FIG. 116.—Fahrenheit thermometer.

The scale of the centigrade thermometer is much more convenient, and is used almost exclusively in scientific work in all countries. In some countries of Europe it is used for all purposes.

The Fahrenheit thermometer has extensive use in the homes, and for ordinary purposes, among English-speaking people.

Both kinds of thermometers should, if possible, be secured, and used in the experiments on heat; but in case this cannot be done, prepare one as described in the following experiment:

Experiment 62.—Secure a common thermometer that is mounted on wood. Remove the cleats and lift out the glass part. Then saw off the lower part of the wooden back at the zero point. Place the glass part back in its place, and the bulb will then project some distance below the wood, as seen in Fig. 117. This will make it convenient to insert the bulb in a liquid or under the tongue, and so on.

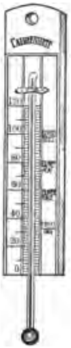

FIG. 117.—A Fahrenheit thermometer.

Expansion caused by heat.—We have already explained that heat is a motion of the molecules of a substance, and that when a body is heated its molecules are made to move faster. As a result, the molecules move back and forth through a greater distance, and so require more room. This causes the whole body to become larger, or expand.

This may be compared to a crowd of boys. When the boys are all nearly quiet, they may stand close together and take a small amount of room. But if each boy begins to jump back and forth, and bump against the others, the crowd will soon be spread over more ground, and may be said to expand.

Experiment 63.—The expansion of a copper wire may be shown by the apparatus here

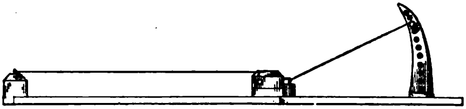

FIG. 118.—Apparatus to measure the expansion of copper wire.

described. Select a board about two feet long and four inches wide. Fasten firmly to one end of it a block about three inches high. Near the other end fasten another block about four inches high and two inches thick, placed so that one side of it is on a line with the middle of the board. To one side of this block, and about one and one-half inches from the top of it, fasten a piece of wood about one inch square and three inches long, so that it will rotate freely about a round nail through a hole in its lower left-hand corner. Fasten to this stick a long pointer and a screw, as shown in Fig. 119. Stretch a copper or iron wire from the screw at the top of this stick to the screw at the top of the first block. The ends of the wire should be soldered to the screws. A convenient weight hung on the end of the rotating stick will keep the wire stretched. By this arrangement, any change in the length of the wire will be plainly seen in the motion of the long pointer.

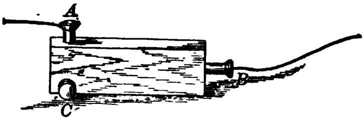

FIG. 119.—Lever block of the expansion apparatus. *C* is the nail about which the block rotates; *B* is the pointer; *A* is one end of the copper wire.

You can see that the stick in the figure is arranged as a lever of the first class. Suppose the distance from the top of the screw, where the wire is soldered to it, to the middle of the nail is two inches, and from the end of the pointer to the middle of the nail is twenty inches, then the pointer-arm would be ten times longer than the screw-arm. So, then, if the wire changes its length one-tenth of an inch, the end of the pointer will move one inch.

When the instrument is set up as shown in Fig. 118, mark the position of the pointer, and heat the copper wire by moving a flame back and forth beneath it. The pointer will move downward, showing that the wire has become longer. Cool the wire with ice or cold water and the pointer will rise.

Carefully measure the lengths of the two arms of the lever and the distance moved by the end of the pointer. From this calculate how much the wire changed its length in the experiment you made.

All bodies tend to expand when they are heated. Solids and liquids expand with very great force, but not through a very great distance. Gases expand very readily with only a very slight change in temperature.

Experiment 64.—Pass a glass tube through a cork, and fit the cork into the neck of a flask. Be sure the cork fits air-tight into the flask and around the tube. Test by suction on the tube. Invert the flask, and place the end of the tube a little way beneath the surface of water. Hold the flask in the hands, and the heat from the hands will cause the air to expand as may be

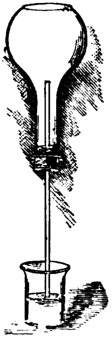

FIG. 120.—Expansion of gases.

seen by the bubbles which escape into the water. Heat the flask slightly with a flame, and many bubbles will escape.

Cool the flask, and the water will rise in the tube, showing that the air has contracted.

Heat will always cause a body to expand, and cold will always cause it to contract. It is no exception to this rule, that water will expand when frozen. The crystals of ice require more room than the same mass of water. Water expands if it is cooled below 4° centigrade, because it then begins to crystallize. The cooling still tends to make it contract, but the crystallization expands it more than the cooling contracts it.

Instances of expansion and contraction.—Long strands of wire fence are often made, the ends of the wires being fastened to strong posts. If the fence be made during cold weather, then when it grows warm the wires will expand and sag. If, then, the wires be drawn up tight and fastened at the ends, the next winter they will contract and pull up the end-posts. Various devices have been invented for changing the length of the wires so that they will remain tightly stretched at all times, and yet not be stretched too tight. The first opportunity you have, observe what some of these devices are.

A good illustration of expansion and contraction may be seen at any blacksmith's shop. A tire must fit tightly on the wheel of a wagon. To do this, the blacksmith first heats the tire to a dull red heat. It will then easily slip onto the wheel. If water be now poured onto the hot tire, it will contract and tightly clasp the rim of the wheel.

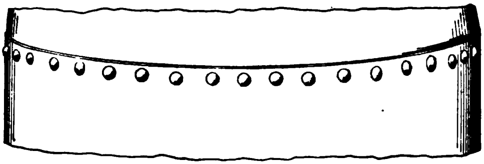

FIG. 121.—Rivets in a boiler.

The same principle is used in boiler-shops, where the overlapping edges of boiler-iron are riveted together. The rivets are hammered into their place while they are red hot. When they become cold, they contract and pull the edges still more tightly together.

In the construction of a railroad track the ends of the rails are not put close against each other. A little space is left at the joints, so that when the rails become warm under the heat of the sun, they will have room to expand. Otherwise the rails would bend out of a straight line.

How heat travels.—There are three ways by which heat travels from one place to another. The first is *conduction;* the second, *convection*, and the third, *radiation*.

Conduction.—When one part of a body is heated, the heat will travel from molecule to molecule to other parts of the body. This is *conduction.* When the point of a poker is placed in the fire, heat will be conducted along the poker to the handle.

There is a great difference in the ability of a substance to conduct heat. Copper and silver are very good conductors. Water, air, and wood are very poor conductors. Iron is a good conductor, but not so good as copper or silver. Lead is not so good as iron.

Experiment 65.—Stretch two wires about two feet long, one copper and the other iron. They may run side by side about one-quarter of an inch apart. Heat the wires with a flame, and rub back and forth on them a piece of paraffine or beeswax. Let the wires cool. Let a flame burn against the two wires as in Fig. 122. The heat will be conducted along the wires, and the distance it has travelled may be seen by melted wax on the wire.

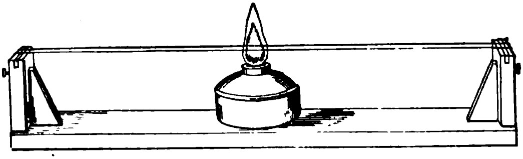

FIG. 122.—Conduction of heat.

It will be observed that the wax is moved to a greater distance on the copper wire than on the iron one, showing that copper is a better conductor.

In this way, tests may be made of the conductivity of wires of various kinds.

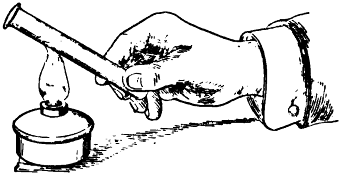

FIG. 123.—Water a poor conductor of heat.

Experiment 66.—Fill a test-tube about three-fourths full of water. Hold it over a flame as shown in Fig. 123. The upper part of the water may thus be boiled for some time, and yet the lower end of the tube will feel as cool as at first. This shows that water is a very poor conductor of heat.

Some uses for poor conductors.—Dry air is a very poor conductor of heat, though this is not easily shown by a simple experiment. We often make use of a body of air when we want a poor conductor.

Ice-boxes are surrounded with a thick layer of ground-up cork and the air between the pieces of cork. Both are poor conductors of heat and keep the outside heat away from the ice.

In the winter-time we wear thick woollen clothing, which holds a great deal of air in the spaces of the loose cloth. In that way the heat of the body is kept in.

In building a house, we enclose a layer of air between the inside and outside walls. By this means the heat is kept out in summer and in during winter.

Smoothing-irons, tea-kettles, and other utensils have wooden handles, because wood is a poor conductor, and the heat is not readily conducted to the hand. This saves many burned fingers in the kitchen.

Steam-pipes are covered with asbestos, because asbestos is a very poor conductor of heat, and thus the heat of the steam is not allowed to escape while it travels from the boiler to an engine or elsewhere.

Such are a few of the numerous applications which are made of non-conductors of heat.

Convection.—Convection is a movement of liquids or gases by which heat is distributed through them. When a body of liquid or gas is heated at the bottom, the part which first receives the heat—the lower layer—becomes lighter and rises to the top, while the cooler parts, being heavier, will sink to the bottom. This movement in the liquid or gas, as a result of heating the lower layer, is called *convection.*

We have just shown that water is a very poor conductor; and, if we had to heat water by applying heat on the top of it, we would probably never succeed. Instead of that we heat the bottom of the kettle, and as soon as the water there is slightly warmed, it moves up through the rest of the liquid. Other water that is colder then comes down to get its load of heat and rise with it as before. Soon the whole body of water becomes as hot as that at the bottom.

Experiment 67.—Fill a flask with water and drop into the water a pinch of pine sawdust. Apply heat to the bottom of the flask, and the convection currents will be made visible by the sawdust which floats in the water.

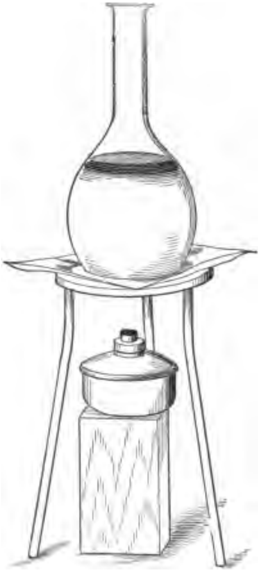

FIG. 124.—Convection of water.

Instead of the flask, a tin pan or other vessel may be used.

Experiment 68.—The convection in gases can be demonstrated by use of the apparatus shown in Fig. 125. The box may be simply a cigar-box, but it must be sealed air-tight. Cut two holes in the lid, each about one-half inch in diameter. Place over each hole a lamp-chimney. Fasten the chimneys tight to the lid by means of wax or putty. Light a piece of candle, and lower it by means of a

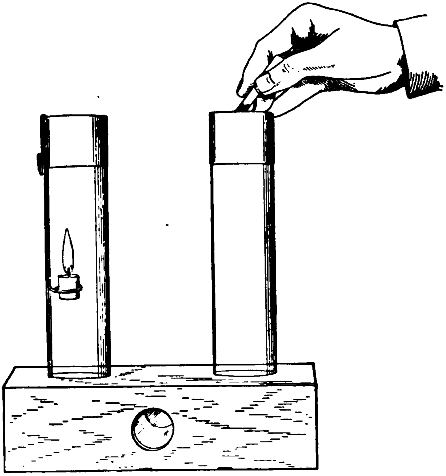

FIG. 125.—Convection currents of air.

wire into one of the chimneys. The air about the candle will be heated and rise, while fresh air will pass down through the other chimney to take its place.

To make this movement apparent, use a roll of the touch-paper which was described in Experiment 18.

Some instances of convection.—If you have ever stood near a large bonfire or other out-door fire, you have noticed a strong movement of the air from all sides towards the fire. The heated air was rapidly rising, as could be seen by the sparks and smoke, and the cooler air, which was heavier, was flowing in to take its place.

This same operation is performed on a large scale when the sun heats the air in one locality more than in another. The warmed air rises by convection, just as it did above the bonfire, and the cooler air rushing towards that locality is the cause of nearly all our winds.

There are great currents in the ocean, such as the Gulf Stream, the Japan Current, and others. These are warm currents flowing from the equator towards the poles. They are convection currents, because there are also cold currents, deep in the ocean, which are flowing from the poles to the equator. The water is heated at the equator and flows out on the surface towards the poles, and back, beneath the surface, to the equator again.

We make a great deal of use of convection. The draft of air in a stove or furnace, by which oxygen is brought to the fuel, is made possible by convection. The burning of a lamp, candle, or gas-jet is maintained in the same way. Many houses are warmed by convection currents from hot-air furnaces. Other houses are heated by hot water, which is carried by convection through the pipes and radiators in the various rooms. Ventilation is in most cases accomplished by convection.

If, in a warm room in winter-time, you will place a thermometer near the ceiling, it will show a much higher temperature there than when placed near the floor. Why is this?

Radiation.—Radiation is the third way by which heat is conveyed from one point to another. Any hot body can start waves in the ether. These waves travel out in all directions, just like the waves of light. They start from a hot body, and will cause heat when they are stopped, but they are only waves—not heat—while they are moving.

Experiment 69.—Sit near a hot stove. The face and hands at once feel the warmth. Hold a screen of any kind between you and the stove, and at once the feeling of warmth ceases. What was stopped by the screen? The air has the same temperature all the time, but the waves are now falling upon the screen instead of upon your face.

On a cold winter day, when the sun is shining, stand near a window and let the sunlight fall upon your hand. You can feel the warmth. Place the hand upon the glass through which the sunlight came, and it will feel as cold as ice. The waves came through the glass, but were stopped by the hand. So the hand, and not the glass, was warmed.

Specific heat.—*Specific heat* of any substance is the amount of heat which it will hold as compared with what the same weight of water will hold. For example, if one pound of any substance can hold only one-half as much heat as one pound of water when both are raised to the same temperature, then the specific heat of that substance is .5. If it held only one-fourth as much, its specific heat would be .25. Water has a great capacity for heat, and the capacity of any other substance is referred to it.

Experiment 70.—Weigh two test-tubes. Fill one of them about three-fourths full of water. Weigh again and find the weight of the water. Then weigh out an equal mass of mercury and put it in the other test-tube. Have a vessel of boiling water at hand, dip the two tubes together into the water for only a few seconds. Test at once with a thermometer, and it will be found that the mercury is much hotter than the water. Both were in the hot water for the same length of time; but, since the mercury cannot hold much heat, its temperature was rapidly raised. Such a substance will also cool off very rapidly. The specific heat of mercury is .033.

The capacity of water for heat.—It is an old saying that the watched pot never boils. Water can hold so much heat that when you wait for it to boil it seems to take a long time. After water once becomes hot, it will remain warm for a long time, because it has so much heat to give out to other bodies.

This will explain why it is a good plan to take a jug of hot water in the sleigh or buggy when making a trip on a cold day. The water will keep the feet warm for a long time, while a hot piece of iron would soon cool off.

The water of a lake receives a great deal of heat from the sun, though its temperature never rises very much. The lake gives off this heat to the trees and vegetation on its islands and along its coasts. Such localities are often good places for fruit-trees, sudden frost being prevented by the heat from the lake.

Latent heat.—When the heat which goes into a body does not change its temperature, it is called *latent heat.* Latent means hidden. It requires a great deal of heat to melt ice, but no amount of heat can change its temperature while it is melting.

All the heat the ice received is latent or hidden. After the ice is changed to water, its temperature will steadily rise until it boils. After boiling begins, the temperature becomes stationary again, and does not change till the water is all changed into steam. It requires a very large amount of heat to change boiling water to steam, and it is all latent.

It requires eighty times as much heat to melt one pound of ice as it takes to raise the temperature of one pound of water 1° centigrade, or, the heat which will melt one pound of ice will raise the temperature of one pound of water eighty degrees centigrade. That is, the latent heat of ice is 80. The latent heat of steam is 536.

Experiment 71.—Pound some ice into fine pieces. Weigh out one pound of it and place it in a glass beaker or small tin can. Weigh out the same quantity of water and pour it in a vessel just like the one which contains the ice. The water must be as cold as ice. It can easily be made so by adding ice to a quantity of water until its temperature falls to zero centigrade. One pound of such water is to be taken. Set both vessels into boiling hot water. Stir the ice constantly, and when it is all melted, the temperature of the water should be zero centigrade, but the water in the other can will have its temperature raised to 80° centigrade. This experiment shows what is meant by saying that the latent heat of ice is 80.

Advantage of latent heat in ice.—We have just shown that ice will not melt until it has received a large amount of heat, called its latent heat. After it is once melted, it cannot be frozen again until all this latent heat is taken out of it. For this reason, water cannot be quickly frozen or ice quickly melted.

If it were not for the latent heat, water would all change to ice as soon as its temperature reaches 0° centigrade or 32° Fahrenheit. As it is, water may be as cold as ice and yet not freeze.

Often in winter-time there are great masses of snow and ice on the ground. When a warm day comes, all this ice and snow would be suddenly melted, and there would be floods of water if it were not for the latent heat. As it is, the snow and ice can melt only as fast as they can get the large amount of latent heat that is necessary.

Other substances also, such as iron and

copper, must receive a considerable amount of latent heat before they can be melted.

Boiling.—Liquids boil whenever their temperature is raised to such a point that they begin to change to a vapor. For example, when the temperature of water is raised to 100° centigrade or 212° Fahrenheit, it begins to turn to steam. The bubbles of steam rise in the water and cause the familiar appearance of boiling water.

Each liquid has its own boiling point, some boiling at a high temperature, and others at a very low temperature. The boiling point of alcohol is 78° centigrade; ether, 35°; mercury, 357°; sulphur, 445°; water, 100°.

The boiling point of a liquid is raised when it contains a substance dissolved in it. The sea-water, for example, must be made hotter than 100° centigrade before it will boil.

Experiment 72.—Pour about one pint of water into each of two flasks or other convenient vessels. Put two or three spoonfuls of salt into one, and apply heat to both until they begin to boil. Take the temperature of each It will be found that the liquid which contains the salt will be hotter.

The boiling point of a liquid is changed when the pressure upon the liquid is changed. We say that the boiling point of water is 100° or 212°. This would not be so if we lived far above sea-level. Water will boil at a lower temperature whenever the pressure is less, and at a higher temperature whenever the pressure is greater.

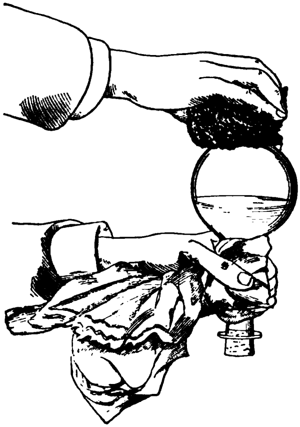

FIG. 126.—Boiling water by removing the pressure.

Experiment 73.—Fill a quart flask about one-quarter full of water, and heat it till boiling begins. Remove the flask from the flame and at once cork it tightly. Hold the flask upsidedown and pour cold water upon it. The cold condenses the steam, and so removes the pressure from the surface of the water. The water will at once begin to boil again, and will continue to boil for some time if the space above it is cooled. When all sign of boiling ceases, remove the cork and take the temperature of the water.

Travellers often tell us of the difficulty they had in trying to cook any food by boiling it in water when they were on a high mountain. The water would boil just as at sea-level, but it would not get very hot. This, of course, was caused by the light air-pressure at that high altitude. It is the heat that cooks the food, and after water once begins to boil it cannot be made any hotter, no matter how hot the fire may be.

Evaporation.—*Evaporation* is a slow process by which many liquids change into a state of vapor. When a body of water is exposed to the air, some of the molecules at its surface are constantly leaving the liquid and going up into the space above it. In the course of time all the water in an open vessel will disappear by this process, called evaporation.

Experiment 74.—Cut out of a piece of blotting-paper a circle about two inches in diameter. Punch a small hole through the centre of it. Fill a test-tube full of water and slip the circle of blotting-paper over the mouth of it. Turn all upsidedown, and place upon a piece of glass a little larger than the blotting-paper. The tube can be supported by a wire bent around the tube and fastened to the board beneath the glass, or as shown in the figure.

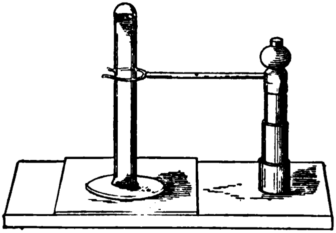

FIG. 127.—Apparatus for testing evaporation.

Place the apparatus in a draft of warm air, and water will evaporate from the wet blotting-paper. The paper will be kept wet by water which runs down from the test-tube as fast as it evaporates from the paper.

In one hour or more note how far the water has fallen in the tube.

Place the apparatus where there is no draft of air, and it will be seen that evaporation is much slower.

Place the apparatus in a cool place, and it will be seen that evaporation is slower than where it is warm.

Some thoughts on the experiment.—Evaporation is more rapid when there is a draft of air. When the space above the surface of the water becomes filled with vapor, no more molecules can come up. A draft of air will blow these away and bring in fresh, dry air, which permits evaporation to continue. This is the reason wet clothes will dry much sooner when the wind is blowing. This is also the reason for fanning our faces on a warm day. The faster the moisture on the face evaporates, the more heat will be taken up. If our faces are perfectly dry, fanning will not cool them.

Experiment 75.—Hang up two thermometers side by side. Wet the bulb of one with water or alcohol, and fan both vigorously.

The one with a wet bulb will show a lower temperature, but the other will not be changed.

The evaporation takes place more rapidly when the air is warm, as we might expect. The molecules are moving faster in a warm liquid, and so more of them would leap out at the surface.

Evaporation is also more rapid when the liquid has a large surface exposed to the air, because there are then so many more places where the molecules can get away. Hot water will cool much faster in a saucer than in a cup, because evaporation can go on faster from a large surface.

Condensation.—It is heat which causes all evaporation. If the air which holds the evaporated water is cooled, the vapor will be condensed and return to water again.

The air from the lungs is full of vapor of water, and you have often observed how easily it is condensed when you breathe against cold glass or into cold air.

Heat takes water into the air, and cold drops it out.

This is the explanation of all rain. Heat keeps the air stored with water-vapor which evaporated from rivers, lakes, seas, and land. Whenever this air is sufficiently cooled, the water will be dropped out of it.

The dew found in the morning can be explained in the same way. If it is cold enough to freeze the dew, it is called a frost.

QUESTIONS.

1. What is heat?

2. How may a fire be started by friction?

3. Give several illustrations of heat caused by friction.

4. Why does a penny get hot when it is struck with a hammer?

5. What is burning?

6. What part of the air causes burning?

7. Describe a method of burning iron wire.

8. What is the effect of nitrogen and argon on a fire?

9. How can you get a jar of nitrogen?

10. What is meant by temperature?

11. What do we mean by the terms *hot* and *cold?*

12. State conditions in which ice may be considered hot.

13. Describe an experiment which shows that the exact temperature cannot be told by the sense of feeling.

14. Describe a thermometer.

15. What are the two kinds of thermometers? How do they differ?

16. Why does a body expand when heated?

17. How can you show that a copper wire will expand and become longer when heated?

18. How can the expansion of gases be shown?

19. Give several instances of expansion and contraction.

20. How does heat travel?

21. What is conduction?

22. How can it be shown that water is a poor conductor?

23. Give several uses for poor conductors.

24. What is meant by convection?

25. Does a stove heat the air in a room by convection or conduction?

26. Give several instances of convection.

27. What is meant by radiation of heat?

28. What is specific heat?

29. Explain the meaning of the saying, "The watched pot never boils."

30. What is latent heat?

31. What is the latent heat of ice and steam? Explain what these figures mean.

32. Why does ice melt so slowly?

33. What causes boiling?

34. What is the effect on the boiling point when salts of any kind are dissolved in a liquid?

35. What effect does pressure have on boiling point?

36. Why can potatoes not be cooked by boiling on the top of a high mountain?

37. What is evaporation?

38. State three ways by which evaporation may be increased.

39. Why does fanning cool the face?

40. What causes rain and dew?

CHAPTER XI

MAGNETISM AND ELECTRICITY

Loadstone.—There is a kind of iron ore called loadstone, or lodestone, which means leading stone. It was so called because it would attract and hold small particles of iron, such as carpet tacks or iron filings. In Fig. 128 is seen a piece of lodestone with iron filings clinging to it.

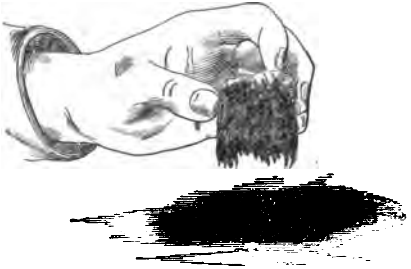

FIG. 128.—Lodestone attracting iron filings.

Such a piece of iron is said to be magnetic, or a magnet.

Lodestone is magnetic in its natural state, that is, it is a magnet when it is dug out of the earth, but any kind of iron may be made magnetic.

Experiment 76.—A piece of iron can be magnetized by a magnet. For this purpose it is best to buy a magnet, either a bar magnet or one of the horseshoe pattern. Get at the jeweller's store a broken watch-spring or clock-spring. Straighten by drawing it between thumb and finger. File or break off a piece

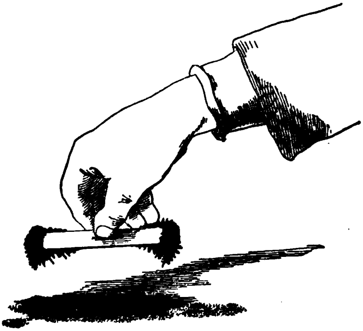

FIG. 129.—Magnet attracting iron filings.

about two inches long. Lay the piece on a table and draw one end of the magnet over it from end to end in one direction only. Make eight or ten strokes with the magnet, being careful to lift the magnet three or four inches above the table in going back for the next stroke.

Then try the piece of watch-spring on some iron filings or carpet tacks. It will act just like the magnet, but may not be so strong.

Try to magnetize a sewing-needle, a knitting-needle, a blade of a penknife, or any small piece of steel.

Two kinds of magnets.—When a piece of steel is magnetized, as just described, it will hold its magnetism and become a magnet. It is called a *permanent magnet.* A piece of soft iron can also be magnetized, but it loses its magnetism as soon as the magnet is taken away from it. It is called a *temporary magnet.*

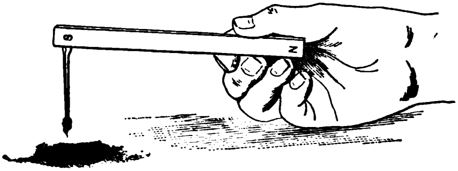

FIG. 130.—A temporary magnet.

Experiment 77.—A horseshoe nail is soft iron. It will be a magnet as long as another magnet is touching it or near to it. Touch the point of the nail to some iron filings while it hangs from the end of the magnet. The filings will cling to it. Remove the nail a distance of one foot or more from the magnet, and the filings will fall off, showing that its magnetism was only temporary.

A law of magnets.—The ends of a magnet are called *poles*. The poles are usually marked + and —, called *positive* and *negative*. One positive pole will repel another positive pole, but will attract a negative pole. The law is,

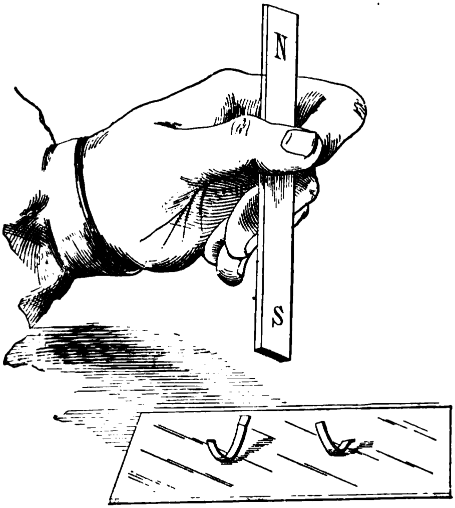

FIG. 131.—Apparatus to illustrate the law of attraction of magnets.

like poles repel one another, but unlike poles attract one another.

Experiment 78.—Magnetize two pieces of a watch-spring, each about one inch long. Bend up the ends and place them on a smooth surface so that they may turn easily. Mark the two positive ends with a small piece of white paper. Place them near to each other. The positive end of one and the negative end of the other will be drawn together.

Bring the negative ends of a magnet near, and both ends carrying the paper will turn towards it. Turn the magnet end for end, and the two small magnets will also turn.

In all cases like poles repel, and unlike poles attract, each other.

The earth a magnet.—When a magnet is suspended so that it can turn very easily, it will stand in a north and south direction. This is because the earth is a magnet, and the suspended magnet is turned so that the unlike poles are towards each other. The end which points towards the north is called the *north-seeking pole*, and the other end the *south-seeking pole*.

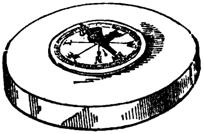

FIG. 132.—A magnetic needle.

Experiment 79.—Purchase a small compass, such as may be found for sale in any town or city. Remove the magnetic needle, and mount it on the point of a fine sewing-needle, as shown in the figure. The base may be wood or a thin piece of cork. The sewing-needle should project not more than one-half inch up through the base, the remaining part being broken off.

However the base may be turned, the magnetic needle will keep its direction north and south.

Further use will be made of this instrument in later experiments.

Any magnet will stand in a north and south direction if it be mounted, or suspended from a fine silk fibre so that there is very little friction.

The compass.—The compass is simply a magnetic needle mounted on a fine point. It is usually enclosed in a box. On the bottom of the box is a card marked North, South, East, and West, with subdivisions between the four points.

The chief uses of the compass are in navigation, surveying, and travelling.

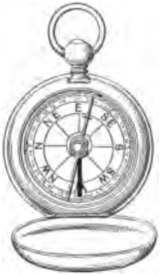

FIG. 133.—A magnetic compass.

Its use in navigation has been known for nearly six centuries. Ships to-day have better compasses, but they are steered by the compass as they were centuries ago.

Since the magnetic needle will point in nearly the same direction year after year, it is useful in surveying land. When a record is made of one survey, the compass can be used years afterwards to find the lines marked out in the first survey.

Travellers often find the compass a valuable guide to help them on their way.

Electrification.—Nearly all bodies can be electrified in one way or another. Electricity is a very common thing and is almost everywhere. Wherever there is friction, there is pretty sure to be electricity.

The metals are *good conductors* of electricity, and so we do not often find them electrified, because the electricity rapidly escapes from them to other bodies they may happen to touch.

Other substances, like hard rubber, glass, and wood, are very *poor conductors* of electricity, and so, when they are electrified, the electricity will remain on their surface and can be examined.

In winter-time, when the air is dry, it is easy to produce electricity by friction. If you find a house-cat lying on a woollen shawl, bring your finger near to her nose, and a spark of electricity nearly one-half inch long will jump to your finger. Stroke the cat in a dark room and sparks of electricity will be seen. The same kind of sparks are often seen when a horse is being curried. On a cold, dry day your whole body may be electrified by walking over a carpet. The shoes, however, must be perfectly dry and should be scraped along the carpet. If, then, you touch another person, they will feel a slight shock.

Numerous instances of this kind of electrification are about us on every hand.

Experiment 80.—Rub a hard rubber comb briskly with a piece of flannel. It will be electrified. Hold it near to pieces of tissue-paper, or other light particles, and notice the result.

Get some pith of a corn-stalk and dry it thoroughly. With a sharp knife make some small balls of the pith a little larger than a buckshot. Suspend two of the balls by fine silk fibres. Hold the electrified comb near the balls. They will at first be drawn to the comb and then will fly off. When the comb is now moved towards them, they will move away from it. The balls are charged with the same kind of electricity that the comb has.

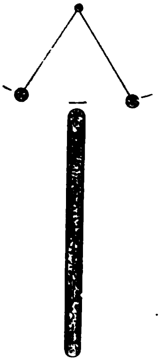

Fig. 134.—Pith-balls repelled by an electrified rod of rubber.

Now rub a glass rod with silk and bring it near the balls while they are trying to keep away from the comb. They will at once be drawn to the glass rod and then will fly from it. They are now charged with the same kind of electricity that the glass rod has. Now, they will be attracted by the comb again.

Some thoughts on the experiment.—There are two kinds of electricity. The kind on the hard rubber is called negative, and that on the glass, positive. These two kinds have opposite effects and will neutralize each other.

When the pith balls held negative electricity, they were repelled by the comb, which was charged negatively. The glass rod then attracted the balls because it had a positive charge.

The law is, *like charges repel, and unlike charges attract, one another.*

Electrophorus.—An *electrophorus* is an instrument for making electricity. The name is large, but the instrument is simple and easily made and operated.

Experiment 81.—Secure two shallow pie-pans, one of good size and the other about two inches less in diameter. Melt enough of rosin to nearly fill the large pan, putting with the rosin a piece of beeswax about as large as half a hen's egg. Pour this into the large pan and set on a level place to cool.

Now fasten a handle of glass or hard rubber to the centre of the small pan. This may be done with wax or by putting a screw through the pan into the handle.

When the rosin is cold, rub or strike it vigorously with some light woollen goods. It will become charged with negative electricity. Set the small pan upon the rosin and touch it with the finger. Then lift it straight up by the handle and bring your knuckle to the edge of the pan. A vigorous spark will leap to your knuckle. Place the pan again on the rosin, touch it, lift it off, and again it will give a spark. This may be repeated many times before it is necessary to again rub the rosin with the flannel. Bring the charged pan near to the pith balls and notice the result.

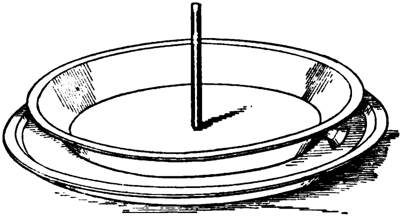

FIG. 135.—An electrophorus.

Leyden jar.—The Leyden jar is a glass jar coated with tin-foil inside and outside. It is used for storing electricity. One can easily be made, and stored by means of the electrophorus described above.

Experiment 82.—Select a glass beaker with straight sides. It may be about two inches in diameter and three or four inches high. Cover it inside and outside, bottom and all, to about three-fourths of its height, with tin-foil. First cut and fit the foil to the surface it is to cover, then fasten it in place with mucilage or flour paste.

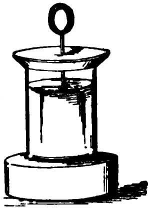
Fig. 136.—A Leyden jar.

Fit a cork into the top of the beaker. A wooden lid will do in place of the cork.

Through the centre of the cork, or lid, pass a wire, which must reach to the tin-foil at the bottom of the beaker and be looped at the top above the lid.

A drinking-glass of good, clear, thin glass may be used instead of the beaker.

Now hold the Leyden jar in one hand, grasping the outer coating of tin-foil. Operate the electrophorus in the manner just described. Bring the upper pan a number of times to the loop of wire at the top of the jar. A spark of electricity will jump from the pan each time and be stored in the Leyden jar.

After three or four panfuls have been

stored, try the jar by touching the loop with one hand while grasping the outer coating with the other. If the jar is a good one you will feel a sharp shock; but there is no danger that this small amount of electricity would do you any harm.

Lightning.—Lightning is electricity of exactly the same kind as that which we have just been discussing. The spark which you saw when it jumped from the pan to your knuckle was in fact a small stroke of lightning, and the snap which you heard was a small clap of thunder.

A stroke of lightning from the clouds is a spark of electricity on a very grand scale. Often the strokes are as much as one mile long. The thunder which we hear is due to a disturbance in the air caused by lightning passing through it.

Franklin's kite experiment.—Benjamin Franklin proved that lightning and electricity are one and the same. During a thunderstorm in the year 1752, he raised a kite high into the air. The lower end of the cord was fastened to a key, and from the key was stretched a silk ribbon to which he held. Dry silk is a poor conductor of electricity.

When the cord became wet, plenty of electricity flowed down the cord to the key. When he held his knuckle to the key, he received a sharp spark. When he held the Leyden jar to the key, the electricity was stored in it just as it is stored from any electrical machine. This experiment shows that there is electricity in the air and clouds, and when a large amount of it flows between the clouds and the earth we call it lightning.

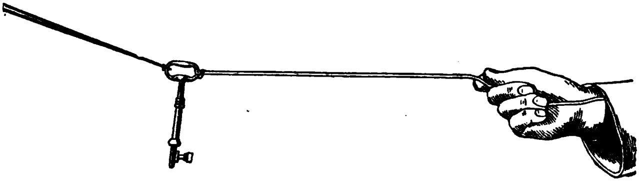

FIG. 137.—Arrangement of silk ribbon, key, and string of Franklin's kite.

Where lightning strikes.—It is impossible to tell where lightning will strike when a storm-cloud hangs over any locality. We can feel quite sure, however, that it will always follow the path in which it meets the least resistance.

Warm air is a better conductor than cold air, and for that reason lightning often comes down the hot air in a chimney.

Metals, as a rule, are good conductors, and lightning often runs along telegraph and telephone wires. For the same reason lightning-rods are put over houses and barns so that, if the lightning should strike at that point, the rods would carry it to the ground.

A tree is a better conductor than air, and so the lightning often follows the tree to reach the ground.

It is dangerous during a thunder-storm to sit near a hot stove, to talk through a telephone, to stand under a tree whether it is large or small, to stand near a wire fence or telegraph post, or to be near to the spouting from a house.

No definite rule can be given for safety from lightning, but lightning is electricity, and will always follow the easiest path it can find.

Current electricity.—All electricity is alike, but it produces very different effects under different conditions ; just as all water is water, but its effects are quite different when it is moving under great pressure or little pressure, and when the quantity of it is large or small.

The electricity which we have just been studying is called *frictional electricity*, because it is produced, often, by friction, as when the rubber comb was rubbed by flannel.

It is also called *static electricity*, because it will stand and can be stored, as in a Leyden jar.

We are now to study what is often called *current electricity*. It is always found to be flowing, like a current, through a conductor, such as a copper wire. It is commonly produced by batteries and dynamos. It is also called *voltaic electricity*, from Volta, an Italian scientist who lived at the beginning of the nineteenth century.

Experiment 83.—A simple battery for producing this kind of electricity may easily be made as follows:

A battery is composed of two or more *cells*. We will here describe the construction of one cell. The figure shows a battery of two cells.

Prepare a block of wood about four inches long and one inch square. Near the centre of it bore two holes about one-half inch apart and one-half inch in diameter. In one of the holes fasten a rod of zinc, and in the other a stick of carbon, by means of screws in the side of the block, as shown in the figure.

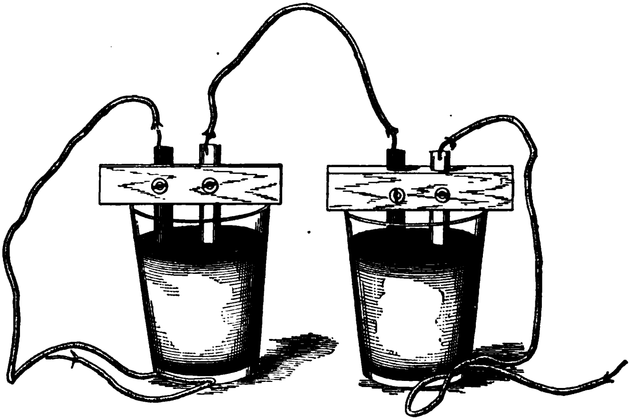

FIG. 138.—Two cells of an electric battery.

Fasten a copper wire about two feet long to the zinc, and one to the carbon. This can best be done by soldering a flat strip of copper to one end of each wire, and inserting the strip beneath the screws and next to the zinc and carbon.

Now set the block upon an ordinary drinking-glass. The zinc and carbon should nearly reach to the bottom.

The liquid must next be prepared. It is made of water, sulphuric acid, and potassium bichromate. This may be prepared in larger quantity than will be needed at once, as new liquid will have to be supplied after the cell has been used for some time.

Into a large glass, or earthenware dish, or a wide-mouthed large bottle, pour about two quarts, or less, of water. Stir into it pulverized potassium bichromate until no more can be dissolved. Then slowly pour strong sulphuric acid in a fine stream into the bottle until the volume of the liquid is increased one-eighth. The liquid will become quite warm when the acid is added. Care must be used in handling this acid, as it is very injurious to nearly everything it falls upon.

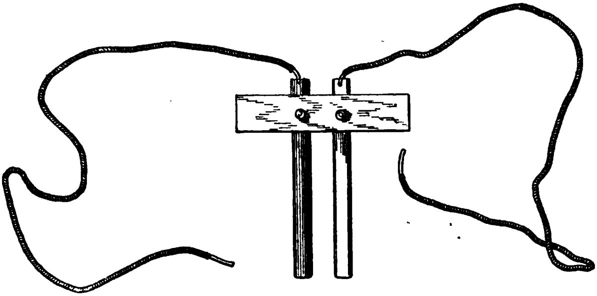

FIG. 139.—Mounting of the zinc and carbon.

When the liquid becomes cool, nearly fill the glass of the cell with it.

Dip the zinc into the liquid and then amalgamate it by rubbing a few drops of mercury over it. The whole surface of the zinc below the block should have a bright, clean appearance. Place the zinc and carbon in the liquid and the cell is now ready for work. When two or more cells are used together, connect the carbon of one to the zinc of the next, the carbon of that to the zinc of the next, and so on. This will leave the two wires at the end free, one connected to a carbon and the other to a zinc. These two wires are to be connected to any instrument which you may wish to operate with an electric current.

In a battery of this kind, the zinc and carbon should be lifted out of the liquid when not in use. After this battery has been used for some time, the current will become weak. Then throw the old liquid out and use fresh liquid.

Names of the parts of the cell.—The zinc and carbon together are called the *elements* of the cell. The zinc is the *positive* element, and the carbon, *negative*.

The ends of the wires are called *electrodes*.

The one connected to the carbon is called the *positive electrode*, and the other, the *negative electrode*.

The current flows from positive to negative. When the two electrodes are connected, the circuit is *closed;* when they are separated, it is said to be *open*. The act of closing and opening a circuit is often called *making* and *breaking* the circuit.

Only the zinc element is affected by the action of the acid. It will gradually waste away and will need to be replaced by a new piece. The carbon does not change.

The current starts at the zinc and flows through the liquid to the carbon; then out on the wire to the positive electrode, thence to the negative electrode and back to the zinc.

The current will not flow except when the circuit is closed. It may be closed through an electric bell, and thus cause the bell to ring. It may be closed through a motor, and thus cause it to run. There are many machines and instruments which may be operated by a current flowing through them.

Electro-magnets.—We have already explained that there are two kinds of magnets, permanent and temporary. A piece of steel may be made a permanent magnet. A piece of soft iron can be made a strong magnet, but it will cease to be a magnet as soon as the influence which makes it a magnet is taken away. When a current of electricity is run a number of times around a piece of soft iron, the iron will become a strong magnet, and will continue to be a magnet as long as the current flows. As soon as the current is broken, the magnetism will cease. Such a magnet is called an *electro-magnet*.

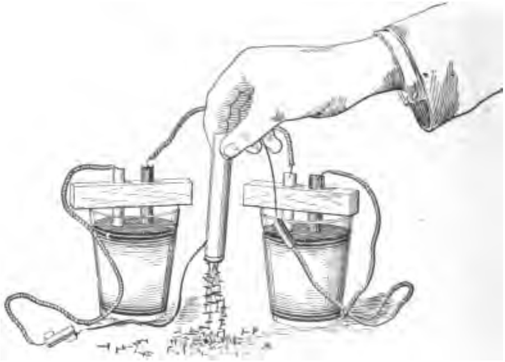

FIG. 140.—An electro-magnet.

Experiment 84.—Select a piece of soft iron about three inches long and having about the diameter of a lead-pencil. Wrap upon it closely, from end to end, two layers of insulated copper wire, leaving about one-quarter inch of the iron projecting at each end. Connect the electrodes of the battery to the ends of the wire on the electro-magnet, and test the magnetism of the iron on some carpet tacks or nails. Break the current and the tacks will at once fall off. The iron, if soft, will be a magnet only while the current flows.

This is the secret of all work in telegraphy. Whenever a current, which may come from a place far distant, flows through an electro-magnet, it will pull down an iron lever and make the dots and dashes. The lever will be held down as long as the operator at another station presses upon his key and keeps the current flowing. When the current is broken, the lever is pushed back by a spring.

The galvanometer.—A galvanometer is an instrument used to tell whether or not a current is flowing through a wire. It is just like a compass, except that the magnetic needle is mounted close to several turns of wire. When a current flows through the wire the needle will be caused to turn so that it will stand across the wire. This will be understood from the experiment.

Experiment 85.—Prepare a smooth pine block about three inches long, two inches wide, and one-half inch thick. Wrap around the middle part of it about twelve turns of insulated copper wire, side by side. Fasten the first and last turn to the block, and leave about two feet of each end of the wire free from the block.

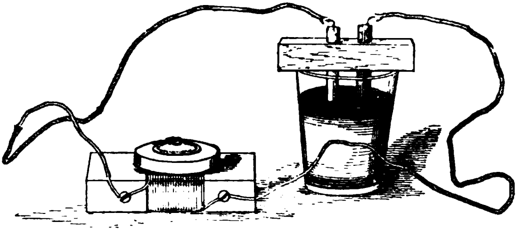

FIG. 141.—Galvanometer.

Place upon this coil of wire the magnetic needle described in Experiment 79. We now have a galvanometer in a very simple form; but it will tell us when a current flows through the wire below the needle, and also about how strong the current is.

The needle will point north and south. Turn the block so that the wires are parallel to the needle.

Now connect one cell of the battery to the coil on the block, and notice that the needle will turn and stand in an angular direction across the wires. Change the connections so that the current may flow through the coil in an opposite direction. The needle will again turn, but in an opposite direction. Thus the needle will not only tell that a current is flowing, but also the direction of the flow.

Connect two cells to the coil. The needle will turn farther than when but one cell was used. So the needle will tell whether one current is stronger or weaker than another.

Plating.—Plating is done by an electric current. A layer of many different kinds of metals may be put upon other bodies by the method of electric plating. Nickel, copper, platinum, silver, and gold are common metals used in plating. It requires a great deal of knowledge and experience to be able to do good work in plating with all these metals. The following experiment in copper plating will illustrate the principle used in all:

Experiment 86.—Dissolve about four ounces of copper sulphate in a quart of soft water. Put this liquid into a glass vessel.

Suspend in the liquid a strip of copper and a stick of carbon, an inch or more apart. Connect the positive electrode of the battery to the copper strip, and the negative electrode to the carbon. It is necessary that the connections be made in this way. The wire from the carbon in the battery must be attached to the copper in the plating liquid, and the other battery wire to the carbon stick in the plating liquid. The current will then flow through the solution of copper sulphate and will carry copper across to the carbon and deposit it on the surface of the carbon. After the current has been flowing for several minutes, raise the carbon and notice how the work is progressing. The longer the current flows, the thicker will be the plate of copper. The copper strip wastes away as the plating progresses.

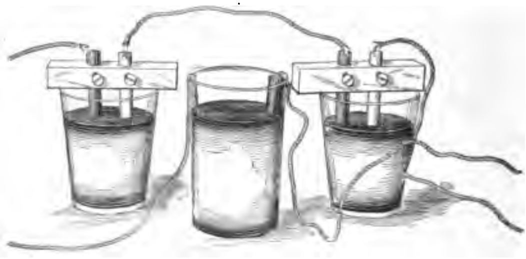

FIG. 142.—Copper plating.

Try also to plate a clean tin spoon or a piece of metal which is already nickel-plated.

This solution will not do for plating iron.

The heating effect of a current.—If the current from a battery of two or three cells be passed through a fine wire, the wire will become hot, and may be made so hot that it will melt. This is because the wire is not large enough to carry the current which is being forced through it, and so it is heated. A larger wire would not become hot, because it could easily conduct the current.

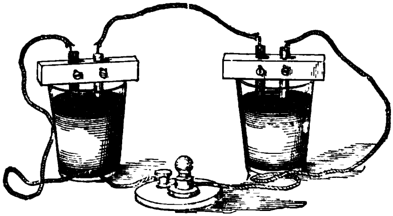

FIG. 143.—The incandescent light.

This is the principle of the incandescent lamp. This lamp contains a fine filament of carbon, and the air is nearly all pumped out of the glass bulb. The filament is made white hot by forcing more current through it than it can easily carry. It will not burn because it cannot get any oxygen.

Small incandescent lamps are made which will light up brightly when connected to two of the cells we have described.

Electric stoves.—Electric cars are often heated by electric stoves placed beneath the seats. This method of heating is also sometimes used in houses. Electric stoves contain wire through which a current of electricity is made to flow. The wire is usually made of German silver, which is a poor conductor of electricity, and so the wire is heated. A small stove of this kind is shown in Fig. 144. The hot coils of wire heat the air, which then rises by convection and carries the heat to all parts of the room.

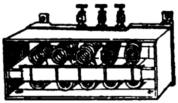

FIG. 144.—An electric stove. The stove is shown lying on its side that the coils of wire within it may be seen.

Coils heated by electricity are often used in cooking. Baking can be effectively done in ovens heated in this manner. Hot plates of this sort can be used in all kinds of cooking. The hot plate shown in Fig. 145 consists of a smooth iron top, beneath which is a long coil of German-silver wire. By simply turning an electric switch, the current is made to flow through the wire. The heat is conducted from the wire to the iron top, and thence to any vessel placed upon it.

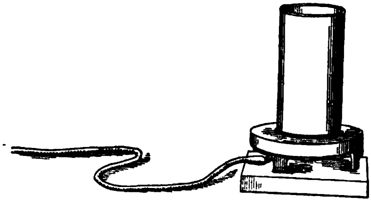

FIG. 145.—An electric cook-stove.

This method of heating and cooking is very convenient and cleanly, but it is not always as economical as other methods.

The arc light.—The arc light is used to light the streets of nearly all cities. It is also in common use in stores, large halls, and shops. It is caused by the intense heating of the ends of carbon rods. When the current begins to flow, the carbon rods are touching each other. Then the rods are pulled apart a short distance, and yet the current continues to flow, but has to jump across the space separating the carbons. In doing this, it heats the ends of the carbons white hot.

The positive carbon becomes hotter than the negative one, so it is placed above, and the negative one below it. In this way the best light is thrown downward.

The heat of the arc light is the greatest we can produce. Any substance like iron, silver, copper, diamond, rock, and so on, will at once be melted if held between the two carbons.

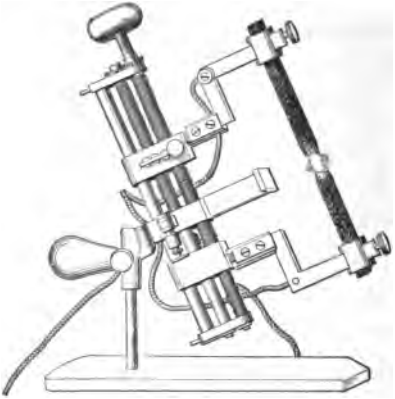

FIG. 146.—The arc light. The carbons and lamp are fed by turning the knob at the top. The current flows from the upper to the lower carbon.

It is very difficult to melt or burn the sticks of carbon as they are prepared, and that is the reason they are used in arc lights. Even they are slowly consumed, and must be replaced by new ones from time to time.

Energy needed for electric lights.—It always requires energy to produce heat and light. We have seen that electricity may be made to produce heat and light in various ways, but we cannot expect electricity for nothing, any more than we might expect tons of coal for nothing. Some people get the idea that, because electricity is so largely used, therefore there should be less use for coal. If such people would visit the electric-light works in towns where coal is used, they would find an arrangement something like that shown in Fig. 147. The pile of coal is the most essential part of it all. Its energy goes into the hot steam in the boiler. The steam turns the engine. The engine turns the dynamo. The dynamo sends out the current which produces the heat and light in the lamp. The energy in the coal is the cause of it all. Whenever the fire in the boiler ceases, the

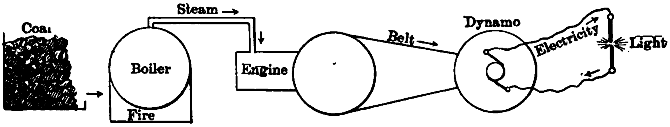

FIG. 147.—From coal to the electric light.

engine and dynamo will stop, and the lights will all go out.

When electricity is used in heating and cooking, it is also at the expense of the coal used at the plant where the electricity is produced. In fact, more coal is used in this way than when it is burned in a cook stove, because a good deal of its energy is wasted before the current reaches us.

Volt, ampere, and ohm.—The pressure of a current of electricity is measured in *volts*. It requires pressure to force a current of electricity through a circuit of wires and lamps, just as it requires a strong pump to force water through the pipes of a water system. The electric pressure is spoken of as the voltage of a current, and it is produced by a battery, the dynamo, or other machine which causes the current to flow.

The size of the stream of electricity is measured in *amperes*. A large pipe may carry a much larger stream of water than a small pipe, though the water is under the same pressure in both. In the same way, a large current of electricity may be flowing under the same pressure as a small one. The large current is then said to have a greater amperage.

We see, then, that a current of electricity may have a very high voltage and at the same time very small amperage. Such a current may have very little energy in it, and may be even passed through the human body without doing any harm.

On the other hand, a current may have very large amperage and very little pressure. Such a current will not flow through any part of a circuit that offers much resistance, for there is little pressure to push it along.

When both the voltage and the amperage are large, then the current contains a great deal of energy and can do a great deal of work.

The resistance offered to the passage of electricity is measured in *ohms*.

Copper wire is a very good conductor of electricity and offers very little resistance. That is why copper wires are so largely used in electrical work.

German-silver wire is not nearly so good a conductor. It resists the passage of a current, and is heated when the current is forced through it. That is the reason it is used when we want the current to produce heat.

The resistance of a 16-candle-power incandescent lamp is about 150 ohms. The common pressure used in such lamps is about 110 volts. The size of the current flowing through such a lamp would be nearly .7 of an ampere.

There are many electrical terms and different kinds of electrical units. The three explained above are in very common use.

QUESTIONS.

1. What is lodestone?

2. How may a piece of watch-spring be magnetized?

3. What are the two kinds of magnets? How do they differ?

4. State a law of magnets.

5. How can you show that the earth is a magnet?

6. What is meant by the poles of a magnet?

7. What is a magnetic needle?

8. What is a magnetic compass?

9. Of what use is the compass?

10. Name some good conductors of electricity.

11. Name some poor conductors of electricity.

12. Name several ways by which electricity may be produced by friction.

13. Describe the experiment with the pith balls.

14. What are the two kinds of electricity?

15. What is the law of attraction and repulsion for bodies charged with electricity?

16. What is an electrophorus?

17. Describe how an electrophorus can be made.

18. How is the electrophorus operated?

19. What is a Leyden jar?

20. How is a Leyden jar made?

21. How does lightning differ from the spark of the electrophorus?

22. What is thunder?

23. Describe Franklin's experiment.

24. What path will lightning follow?

25. What objects are apt to be struck by lightning?

26. What is meant by *frictional* electricity?

27. What is meant by *current* electricity?

28. Describe how a simple voltaic cell may be made.

29. What is meant by the *elements* of a cell?

30. What are the electrodes?

31. What is meant by making and breaking a circuit?

32. What is the path of a current in a battery?

33. When will a current flow?

34. What is an electro-magnet?

35. Describe how an electro-magnet can be made.

36. How is the electro-magnet used in telegraphy?

37. What is a galvanometer?

38. Describe the use of a galvanometer.

39. How is plating done?

40. Describe the method of copper plating.

41. How is an incandescent lamp made, and why does the filament not burn up?

42. What is an electric stove?

43. What use is made of electricity in cooking?

44. How is the arc light made?

45. Why are carbons used in arc lights?

46. Show how energy is needed in producing electric lights.

47. What runs the dynamos at Niagara Falls?

48. Explain the volt.

49. Explain the ampere.

50. Explain the ohm.

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